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Manned Undersea Science and Technology

FISCAL YEAR 1972 REPORT

PENNSYLVANIA STATE UNIVERSITY
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U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

ROCKVILLE, MD.
AUGUST 1973

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U.S. DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

Manned Undersea Science and Technology Program

FISCAL YEAR 1972 REPORT

U. S. Depository Copy

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Introduction

This, the first annual report of the Manned Undersea Science and Technology Program of the National Oceanic and Atmospheric Administration, describes the character and function of the program, its place in the Federal Government structure, and its relationship with State agencies, academic and other nonprofit institutions, and industry. The purpose of the program is to foster manned, underwater scientific investigations in the national interest and the supporting technology needed to complete such investigations safely and expeditiously.

With a total fiscal year 1972 funding of $1,500,000, primary emphasis was placed on conducting scientific operations using existing underwater facilities. Also it was possible to achieve modest technology improvement and to begin a series of user requirement studies. The scientific operations were performed with the advice and review of various governmental and institutional groups and individuals and with investigators whose basic science programs had ongoing Federal, State, and academic funding.

This report reviews the organization, undersea facilities used, and the accomplishments of various underwater, scientific operations off the three U.S. coasts, the Bahama Islands, British Honduras (Belize), and in the Bering Sea. Important new data on reef ecology, pollution and marine biology, and geology were gathered by divers from habitats or by observations and samples obtained by leased submersibles. Fiscal year 1972 was also a year of planning for advanced scientific and technological endeavors, especially those identifying new initiatives for underwater exploration and assessment and assisting in the national quest for new fuel, food, and mineral resources.

Background

The National Oceanic and Atmospheric Administration's (NOAA) program relating to manned underwater activities was formed to fulfill part of NOAA's responsibility for significantly increasing our knowledge of the ocean's resources and processes. Impetus for its formation came from the recommendations of the National Marine Council, various advisory panels, and the Commission on Marine Science, Engineering, and Resources. The goal of the program is to develop, promote, and support a civilian, operational capability for man to work under the sea to achieve a better understanding, assessment, and use of the marine environment and its resources.

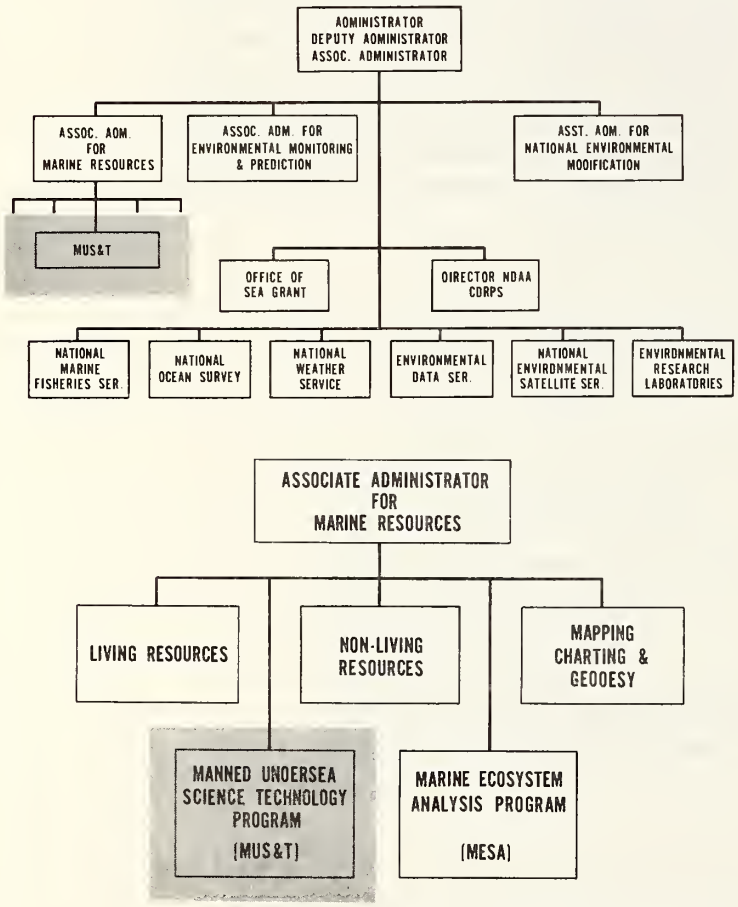


Figure 1.—Location of MUS&T in NOAA organization.

Although initial funds for the program were not available until August 9, 1971, staffing and planning began in December 1970. During the intervening period individuals experienced in the marine sciences and engineering were acquired on a transfer, loan, or an ad hoc basis to plan a national manned underwater program. This program came to be known as the Manned Undersea Science and Technology Program (MUS&T). It was assigned to the NOAA Associate Administrator for Science and Technology until September 1971, when it was transferred to the Associate Administrator for Marine Resources. Figure 1 shows the position of MUS&T at the end of FY1972 within NOAA and the Office of Marine Resources.

Because of the availability of existing manned platforms and budgetary constraints, it was decided early to lease rather than purchase operational systems for field scientific programs and to supply these platforms to principal investigators with ongoing science programs funded by such groups as National Science Foundation, Atomic Energy Commission, Environmental Protection Agency, Office of Naval Research, and NOAA. Leasing was by contracts and grants to both universities and operators of the platforms based upon competitive and sole source procurements. For maximum cost effectiveness, multipurpose programs involving several organizations were implemented whenever possible, particularly when such programs took place in a single geographical region. Later sections of this report show the extent to which other agencies, academic institutions, and industry were involved.

The scientific and technical programs themselves were selected from unsolicited proposals, and competitive procurement was used where possible. Proposals were reviewed by members of the MUS&T staff and by independent outside reviewers. The criteria for selecting programs were based on national goals and priorities and recommended areas of scientific investigation.

Objectives

The basic objectives of the Manned Undersea Science and Technology (MUS&T) program are as follows:

1. Establish quantitative scientific and technical criteria for future civilian, undersea facilities and platforms by using available technology, habitats, and submersibles.

2. Foster and support civilian undersea technology and science projects in conjunction with other Federal agencies, industry, and universities to obtain data and information for better understanding and use of marine resources. This includes providing scientific and diver support and sensor equipment.

3. Develop a NOAA civilian diving program, including rigorous physiological diving criteria to assure safe operations and diver efficiency over prolonged manned missions to Continental Shelf depths of 600 feet.

4. Develop advanced ocean floor laboratories and submersible systems with relative independence from surface support and communications, navigation, and life support systems. These would provide the advanced platforms from which man would obtain the information on the oceans, required on a continuing basis, for contribution to such national goals as marine resource exploration.

To accomplish these objectives, a small interdisciplinary staff of marine scientists, engineers, physiologists, operations research analysts, and program managers was established during fiscal year 1972 in the program office (fig. 2).

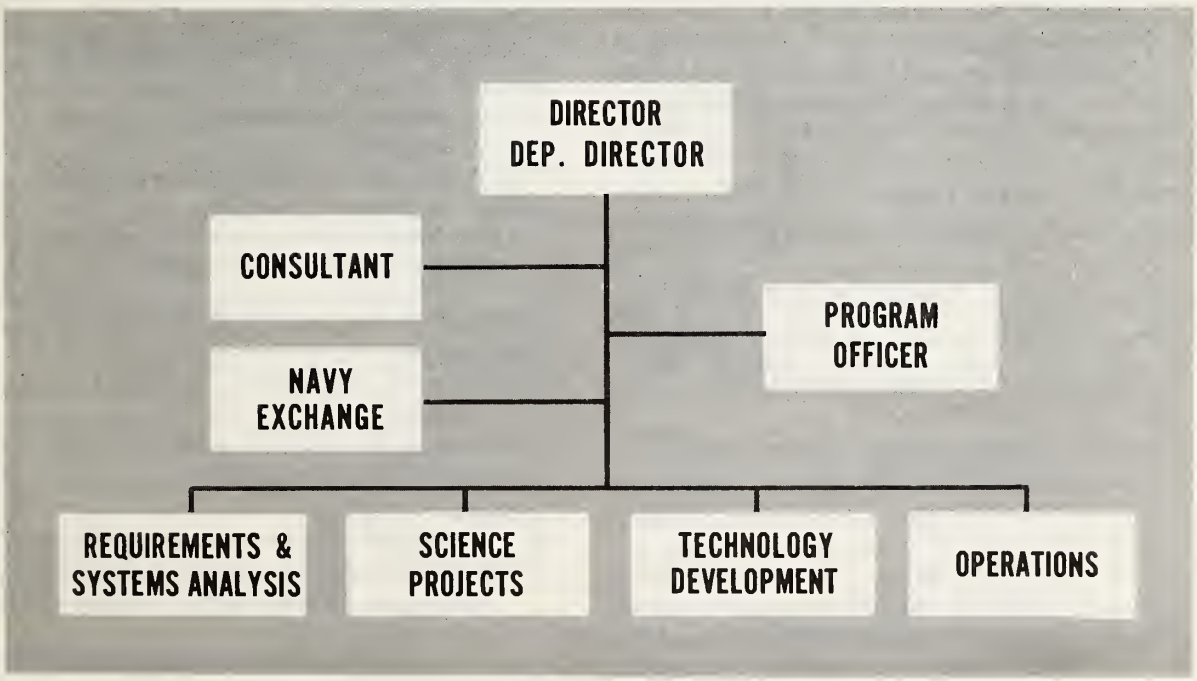


Figure 2.—Manned Undersea Science and Technology (MUS&T) office structure.

Program Structure

OVERVIEW

The general areas into which MUS&T program content was placed are as follows:

☐ Science project areas
- Living resources
- Nonliving resources
- Marine management
- International and national cooperation

☐ Technology development areas
- Diving physiology and technology
- Undersea laboratories and habitats
- Submersible systems
- Support systems

☐ Requirements and systems analysis
- Requirements studies
- Operations research analysis

☐ Operations
- Field procedures
- Diving and submersible safety

A more complete structure showing detailed areas of interest is as follows:

SCIENTIFIC OPERATIONS

☐ Living resources and environmental surveys
- Assessment and location
- Evaluation of assessment and harvesting techniques
- Life cycle studies and biological productivity
- Ecology and environmental surveys
- Supporting investigations

☐ Non-living resources, geology and processes
- Assessment and location
- Evaluation and impact of recovery techniques
- Formation processes
- Geological processes
- Supporting investigations

☐ Marine management and pollution
- Pollutant impact and assessment
- Pollutant indicators
- Sediment and pollutant transport
- Marine mapping and description
- Oceanography
- Supporting investigations

☐ International/national scientific cooperation
- U.S.–French bilateral program
- U.S.–Canadian bilateral program
- Supporting investigations

TECHNOLOGY STUDIES AND DEVELOPMENT

☐ Diving technology
- Diving physiology
- Diver life support equipment
- Diver tools and scientific equipment
- Diver navigation and communications

☐ Undersea laboratory systems
- Laboratory characteristics, designs, and evaluations
- Laboratory scientific and analytic equipment
- Laboratory subsystems and components

☐ Submersible systems
- Submersible characteristics, designs, and evaluations
- Submersible data acquisition systems and components
- Submersible subsystems and components
- Submersible diver lockout systems

REQUIREMENTS AND SYSTEMS ANALYSIS

☐ Program goals and applications
- Manned undersea activity goals and applications
- Benefits from manned undersea activities
- Regional needs and benefits

☐ Program evaluations
- Effectiveness of manned undersea activities
- Cost effectiveness of manned undersea activities
- Accomplishments of manned undersea activities

The general structure for Science Operations was based on the recommendations of a NOAA ad hoc panel and interactions with the marine science and engineering communities. These recommendations

represented an initial concept of key areas of scientific work, where there are potentially valuable applications of manned undersea activities, and where data could be developed for diver support operations. Technology development concepts were based on known areas of equipment or technical deficiencies and deficiencies which are uncovered during science projects using available undersea platforms.

The field scientific efforts required a variety of management structures because of the multiorganizational nature of the projects. In general the operations were directed by the principal investigator or an individual assigned by the contractor. The technology programs were under the direction of a principal investigator selected by the contractor or grantee and whose basic support came from other agencies. The MUS&T program office usually provided an on-site advisor or consultant.

Subsequent sections of this report discuss the individual programs and a brief review of results.

FISCAL YEAR 1972 TECHNOLOGY PROGRAM

The objective of the technology program is to provide safe and versatile undersea vehicles, platforms, and ancillary equipment to facilitate the development of marine resources. The Navy and industry have accumulated much technical knowledge and hardware applicable to MUS&T programs. Though in some cases it may be necessary to adapt available technology to a particular undersea use, in the area of undersea vehicles and platforms like submersibles and habitat basic systems, development does not appear necessary at this time. For example, in FY1972 eight submersibles and two habitats were used, practically unmodified, in MUS&T activities. Thus the main hardware-oriented effort in FY1972 was a survey and assessment of available technical systems to determine their adequacy and safety for use in the MUS&T missions planned. Such an assessment will be continued in FY1973.

Most of the remaining work in FY1972 pertained to diver health and safety. Although Navy, commercial, and university diving organizations have been acquiring technological and physiological diving data for years, a broader data base is needed for the extended and specialized diving activities practiced by marine scientists.

Thus included in the overall MUS&T program were diving technology and physiology, undersea habitats and laboratories, and submersibles.

Diving Technology and Physiology

Diving manual.—A civilian diving manual primarily for scientific and working divers on NOAA-sponsored projects was started. The manual covers physiology, diver equipment, diver procedures, safety, NOAA diving regulations, and other vital areas. Data from the U.S. Navy, academia, and industry are being considered and integrated into the manual wherever applicable. When completed in CY 1973, the manual will be available through the Superintendent of Documents, U.S. Government Printing Office.

Vertical excursion limits.—Research to determine vertical excursion limits for divers saturated at various depths on nitrogen-oxygen breathing mixtures was started. This research promises to open new depth capabilities without the burden of long decompression to permit more effective diving from ocean floor laboratories on the Continental Shelf. Prior to this investigation, little had been accomplished using these breathing mixtures. Nevertheless, vertical excursions with no decompression, simulated in hyperbaric chamber tests, so far have been free of decompression sickness and nitrogen narcosis to greater depths and for longer durations than previously thought possible on nitrogen-oxygen breathing mixtures.

Long-term divers' health considerations.—With more and more diving by NOAA, MUS&T initiated cooperative efforts in FY1972 with the Navy to systematically take long bone X-rays of NOAA divers to study aseptic bone necrosis and possible methods for its prevention.

ASEPTIC BONE NECROSIS

Aseptic bone necrosis may be caused by tiny bubbles forming in the small blood vessels, resulting in reduced blood flow to the bones. This reduction in circulation causes portions of the bone to die. The disease is thought to be associated with the formation of residual bubbles following exposure to increased pressure such as in diving. It can also result from other maladies such as alcoholism and sickle cell anemia.

Surveys in the last 2–3 years in the U.S. and abroad have revealed a significant incidence of aseptic bone necrosis in caisson workers and commercial divers (30–50 percent). In most cases there were no symptoms; in some, however, complete disability has resulted.

Liaison has been established with the Navy to participate directly in a long-term study for determining the development, extent, and seriousness of aseptic bone necrosis in divers. The program consists of obtaining repeated X-rays of prescribed bone and joint areas from a large population of NOAA-supported divers over a period of years. The X-rays will be forwarded to an interpretation center designated by the Navy for evaluation and retention. The results of the evaluation will be forwarded to

NOAA and become part of the MUS&T records and the individual diver's medical history.

BUBBLE DETECTION

When divers spend long periods of time at depth, their bodily tissues and blood absorb part of the nitrogen contained in the breathing mixture. In order to prevent this gas from coming out of the solution too fast and forming bubbles (referred to as bends), divers exposed to higher pressures must be slowly returned to surface pressure. This process of decompression may take hours or weeks, depending upon depth, time at depth, and the breathing mixture used. Decompression schedules over the years have been developed by laborious computation and trial-and-error experimentation. Although computers have accelerated the computation, experimental validation is still required in high-pressure chambers. Recently, several techniques have been used to detect bubble formation in blood and tissues in real time so that decompression could be faster and safer.

One of the most promising approaches involves the use of ultrasonic energy. When such a sound source is properly focused on parts of the body during decompression there is a Doppler shift in frequency as bubbles pass by. Existing devices are to be utilized, evaluated, and modified as part of the MUS&T–Navy program to safely accelerate decompression and thus reduce costs and requirements for using decompression facilities.

Undersea Habitats and Laboratories

The status of available undersea habitats and laboratories as of July 1, 1972, is noted in table 1. Two of these, *EDALHAB* and *HYDROLAB*, were used for science projects during FY1972.

The trends in habitat and laboratory design during FY1972 were for (a) increased transportability to facilitate deployment and subsequent redeployment, maintenance, and overhaul, and (b) providing more space for laboratory facilities compared with systems limited only to living space. Hence the term "undersea laboratory" has emerged to differentiate from a simple habitat, which is primarily intended for living space. Brief descriptions of *EDALHAB* and *HYDROLAB* and their use in FY1972 science projects follow.

EDALHAB.–The University of New Hampshire's undersea habitat Engineering Design and Analysis Laboratory Habitat (*EDALHAB*) was leased and deployed off the southeast coast of Florida in support of the Florida Aquanaut Research Expedition (FLARE). During this project *EDALHAB* was supported by the Navy's catamaran research vessel *LULU*. The combination provided lodging, transport, and backup services for scientific teams investigating the geology, environment, natural history, and ecology of coral reefs. *EDALHAB* was lowered from *LULU* to a depth of 45 feet where it was ballasted to the bottom on its four adjustable legs. This depth

Table 1.–LISTING AND STATUS OF UNDERSEA HABITATS AND LABORATORIES

NAME	OWNER	OPERATIONAL DEPTH (feet)	STATUS (AS OF JUNE 30, 1972)
EDALHAB	University of New Hampshire	45	Inactive; last used in Project FLARE, Florida, Jan. to Apr. 1972.
HYDROLAB	Perry Foundation	50	Used in Bahama Banks research programs, Jan. to June 1972.
TEKTITE	General Electric	80	Inactive; last used in 1970 *TEKTITE II* project in Virgin Islands.
PRINUL	Puerto Rico Undersea R&D Company	100	Completion in Sept. 1972. Operations start in Puerto Rico Nov. 1972.
AEGIR	Makai Range	550	Inactive; last used in Hawaii, 1971, by U.S. Navy.
SANCTUARY	University of Rhode Island	50	Inactive.
LAKE LAB	University of Michigan	50	Formal launching planned for August 1972.

permitted divers to operate in a wide circle around the habitat and obviated the need for special breathing apparatus. The characteristics of *EDALHAB* are as follows:

Depth capability	100 ft
Size	8 ft diameter X 11 ft cylinder
Volume	Approximately 560 cu ft
Weight	28,000 lb
Number of divers accommodating	2–4

The characteristics of the surface support ship *LULU* are as follows:

Hull type	Catamaran
Length	102 ft
Beam	48 ft
Displacement	500 tons
Speed	6 knots
Hoist capability	30 tons
Crew size	11

The support ship also carried a decompression chamber for decompressing the divers saturated on air of 80 percent nitrogen and 20 percent oxygen.

In this project, *EDALHAB* served as a useful undersea platform for conducting uninterrupted scientific experiments in situ, and the *EDALHAB–LULU* combination proved the merits of transportability for an undersea habitat.

HYDROLAB.—The Perry Foundation's (Fla.) undersea habitat *HYDROLAB* was leased and then deployed about 1 mile off the southern coast of Grand Bahama Island at a depth of 50 feet. Its characteristics are:

Depth capability	100 ft
Size	8 ft diameter X 16 ft cylinder
Total volume	730 cu ft
Weight	134,000 lb
Number of divers accommodating	3–4

The habitat is supported via an "umbilical" cable to a 23-foot-long surface life support boat providing the following:

7.5 kW, 110 volt AC via diesel-electric generator

Air compressor

Water supply

Habitat vent hose

CB radio link to shore

Emergency battery power—3-day supply

The habitat will continue to be used in science projects during FY 1973.

Research Submersibles

A survey and assessment of submersibles was made and will be continually updated. Table 2 lists the 13 nonmilitary submersibles that are American Bureau of Shipping (ABS) classed or have been Navy certified. The table also lists one submersible which has ABS classification pending. Eight submersibles were used in FY 1972; of these, only *DEEP DIVER* is shown as not certified, having since been retired from service. The remaining seven used in FY 1972 are listed as follows with their most significant characteristics:

Johnson *SEA LINK.*—The operational depth of this submersible is 1,000 feet. Its transparent hull gives unlimited visibility, virtually without distortion, to the front and sides for pilot and scientific observers. The aluminum diver's chamber allows three divers to lock out underneath the vehicle. The submersible can cruise at 1.5 knots for 8 hours, is equipped with obstacle avoidance sonar, and has a payload of 1,100 pounds including the crew.

Perry *PC 8.*—This submersible has an operating depth of 800 feet. It is equipped with two manipulators and has a payload of 750 pounds including the crew of two. The vehicle has a cruising speed of 1 knot with an endurance of 8 hours. Maximum speed is 4 knots. In addition to nine 8-inch view ports in the conning tower, the submersible has a large, acrylic, forward window consisting of a 114-degree spherical segment.

Perry *DEEP DIVER.*—This lockout submersible is capable of diving to 1,250 feet. It carries a pilot and observer in the control sphere and two divers in the diver chamber. The diver chamber can be mated with a deck decompression chamber permitting saturation diving. *DEEP DIVER* was retired from service in July 1972.

Westinghouse *DEEP STAR 2000.—DEEP STAR 2000* is designed to carry three men to depths of 2,000 feet for operations up to 8 hours at a cruising speed of 1 knot. The submersible has a payload of 500 pounds of scientific equipment. *DEEP STAR* has a manipulator, external viewing lights, and TV cameras and can be equipped with side-looking sonar and sampling and coring devices.

U.S. Navy *ALVIN.—ALVIN* is a deep diving research vehicle designed specifically for oceanographic research. Operated for the Navy by Woods

Table 2.—CHARACTERISTICS AND STATUS OF SUBMERSIBLES, APRIL 1973

NAME	DEPTH (feet)	ACTIVE	CERTIFICATION			LOCKOUT	REMARKS
			ABS	ABS PENDING	NAVY		
ASHERAH	600	Yes	No	No	No	No	
TECH DIVER	600	Yes	No	No	No	No	
SEA RANGER	600	Yes	No	No	No	No	Undergoing trials
SUBMANAUT	600	No	No	No	No	No	
PC-8	800	Yes	Yes	–	No	No	Overseas
SHELF DIVER	800	Yes	Yes	–	No	Yes	Overseas
GUPPY	1,000	Yes	Yes	–	No	No	Tethered
NEKTON ALFA	1,000	Yes	No	No	No	No	
NEKTON BETA	1,000	Yes	Yes	–	No	No	
NEKTON GAMMA	1,000	Yes	Yes	–	No	No	
SNOOPER	1,000	Yes	No	No	No	No	
SEA LINK	1,000	Yes	Yes	–	No	Yes	
BENTHOS V	1,000	Yes	No	No	No	No	
SEA RAY	1,000	Yes	No	No	No	No	
PC-9	1,200	Yes	Yes	–	No	No	Overseas
STAR II	1,200	Yes	No	No	No	No	
OP SUB	1,200	Yes	No	Yes	No	No	Overseas, tethered
DEEP DIVER	1,250	No	No	No	No	Yes	
DEEPSTAR 2000	2,000	Yes	Yes	–	Yes	No	
STAR III	2,000	No	No	No	No	No	
BEAVER MK IV	2,000	No	Yes	–	Yes	No	Ready spring 1973
DEEP STAR 4000	4,000	No	No	–	Yes	No	
DOWB	6,000	No	No	No	No	No	
ALVIN	6,000	Yes	No	No	Yes	No	12,000 ft summer 1973
DEEP QUEST	8,000	Yes	No	No	Yes	No	
ALUMINAUT	15,000	No	No	No	Yes	No	

Hole Oceanographic Institution, *ALVIN* is capable of diving to 6,000 feet and cruising at 1 knot for 12 hours. During FY 1973 the depth capability of *ALVIN* will be increased to 12,000 feet. Four viewing ports permit the pilot and two observers to see ahead and beneath the vehicle. The submersible is equipped with a manipulator, scanning sonar, and closed-circuit TV.

General Oceanographics' *NEKTON BETA* and *GAMMA.*—These small, two-man submersibles have an operating depth of 1,000 feet. Their light weight (4,700 lb) and small size (15 1/2 ft) make them easily transported and handled at sea. Normal submerged speed is 2 knots with an endurance of 8 hours. The vehicles are equipped with a simple mechanical manipulator and have a payload of 450 pounds. Their 17 ports permit unrestricted viewing and distortion-free photography or TV. High-intensity lights and scanning sonar increase the submersibles' capabilities.

Lockheed's *DEEP QUEST.*—This large research submersible has an 8,000-foot operating depth, a maximum submerged speed of 4 knots, and an endurance of 18 hours at 2 knots. *DEEP QUEST* is designed to support a broad range of scientific and research projects and is equipped with a variety of work systems and interchangeable payload modules. Payloads in excess of 2,000 pounds net weight can be installed in addition to two manipulators. The vehicle

is equipped with sonar, an on-board computer navigation system, external TV and lighting systems, and an electronic data collection and storage system. *DEEP QUEST* carries a crew of two, with two additional observers.

REQUIREMENTS AND SYSTEMS ANALYSIS

Major FY 1972 activities were the following:

National civil undersea goals.—During the early spring of 1972 the National Academy of Sciences (NAS) and the National Academy of Engineering (NAE) advisory committee to NOAA recommended that there be a "Study of Civil National Goals for Undersea Science and Technology Requiring Man's Presence and Methods of Achievement." A contract was awarded in late June 1972 to the NAS and NAE for the study through a Manned Undersea Activities Workshop under the auspices of the NAS Ocean Affairs Board and the NAE Marine Board. Industry, academia, and Government, representing all major fields and pro and con positions, will participate in the 1-week workshop scheduled for October 1972, with the final report to be issued during the spring of 1973. The results will be used to revise and support the MUS&T program structure, as necessary, and to aid other activities with undersea missions and interests.

Federal agency coordination.—While interest in the use of manned undersea platforms seemed high and gaining among Federal agencies, there was a continued erosion of those facilities which remained from the building boom of the 1960's. Thus, the Interagency Committee on Marine Science and Engineering (ICMSE) requested in May 1972 a study of the current utilization of the facilities by ICMSE members, of ICMSE members' future requirements for them, and a plan of action to coordinate the use of such needed facilities. A survey was started that month, with the results and analysis to be presented at a later date.

Undersea facility characteristics.—A grant was awarded in June 1972 to the University of New Hampshire's Engineering Design and Analysis Laboratory to "Determine the Impact of the Requirements of the U.S. Scientific Community on the Design of Underwater Manned Platforms." Concentrating on undersea laboratories, the study stresses the uses which scientists wish to make of the platforms, the potential rate of use of platforms, and how the applications affect utilization of existing systems and design of future systems. Since the research and development activities of many scientists are Federal supported, the results will complement information from the ICMSE survey and the NAS/NAE Manned Undersea Activities Workshop. The report to be completed in FY 1973 will influence MUS&T planning for additional facilities and for augmenting, modifying, and using existing facilities.

Support equipment analyses.—Based on needs for additional physiological data on divers, the MUS&T office collected and assembled information on monitoring and analytic equipment. This review led in part to the planning of cooperative ventures in the field.

Data management.—Marine data management and especially information dissemination suffer in common with data management in other disciplines from inadequate storage, retrieval, and analysis capacity and restricted communication channels. Thus, the MUS&T office began a working liaison with NOAA and other data management groups during FY 1972. The various storage and retrieval data groups were notified of MUS&T's programs and plans, and a mechanism for MUS&T cooperative data acquisition and dissemination was formulated. MUS&T experimenters are required to submit preliminary and final data to NOAA's Environmental Data Service, and other forms of communication, such as early publication, are encouraged.

Since much underwater data is analog and pictorial, a picture storage and indexed rapid retrieval system was established within the MUS&T office, and duplicates of all pictures, films, slides, etc., were sent to the National Oceanographic Data Center of the NOAA Environmental Data Service.

Facilities Employed

Basic to any underseas program is the platform used to carry the investigators beneath the sea. In April 1971 a sources-sought notice was placed in the Commerce Business Daily. The replies to this notice formed the basis of the MUS&T file of available platforms. In addition, telephone and letter contact with submersible and habitat operators provided information that assisted in selecting platforms for the first year's projects.

In selecting a vehicle for a project, consideration was given to each vehicle's capabilities, location, cost, and availability. In most cases only one vehicle had

the proper combination of the above factors for successfully completing a given project. Table 3 shows the submersibles and habitats used in MUS&T projects during the year. In addition the Johnson *SEA LINK* submersible[1] was used briefly for lockout training in preparation for saturation lockout[2] diving from the Perry *DEEP DIVER* in the Gulf of Maine. Although not a MUS&T project at the time, the MUS&T office arranged for the Navy to provide an opportunity for scientists from Scripps to make a dive in the Navy's Deep Submersible *SEA CLIFF* near San Diego, Calif.

[1] Owned by the Smithsonian Institution.

[2] This type of submersible has separate compartments for the divers and crew. Upon reaching the desired depth, the pressure in the divers' compartment is equalized with the surrounding water. The habitat can then be opened, permitting the divers to exit and enter freely in the submerged state.

Table 3.—SUBMERSIBLES AND HABITATS USED IN MUS&T PROJECTS, FISCAL YEAR 1972

PLATFORM	OWNER	DATE USED	DIVES (number)	LOCATION	PURPOSE
ALVIN	Woods Hole Oceanographic Institution	10/71	13	Straits of Florida	Geology
ALVIN	do.	6/72	17	Hudson Canyon	Geology, pollution
DEEP DIVER	Perry Oceanographics	5/72	29	Gulf of Maine	Fishery biology
DEEP QUEST	Lockheed	6–7/72	8	Southern California	Pollution survey, geology
DEEPSTAR 2000	Westinghouse	7/72	6	New York Bight	Pollution survey
EDALHAB[1]	University of New Hampshire	2–4/72	106	Florida, southeast coast	Biology, geology, reef ecology
HYDROLAB[1]	Perry Oceanographics	11/71 5–6/72	201	Grand Bahama Island	Biology, reef ecology
NEKTON BETA	General Oceanographics	12/71	30	British Honduras	Geology
NEKTON GAMMA	do.	6/72	16	Gulf of Mexico	Reef survey
PC-8	Perry Oceanographics	9/71	33	Gulf of Maine	Fishery biology
PC-8	do.	10/71	13	New York Bight	Pollution survey
PC-8	do.	12/71	7	Bahama Banks	Geology
PC-8	do.	2/72	4	Bering Sea, Alaska	Pacific walrus study

[1] Habitat.

Scientific Operations

Operational projects were conducted on all three U.S. coasts, in British Honduras, the Bahamas, and the Bering Sea (fig. 3). These projects used eight different research submersibles and two ocean floor habitats. Personnel participating in them came from universities, industry, Federal and State agencies, and Canada. Some of the programs were sponsored solely by the MUS&T office, whereas others were supported jointly with other NOAA components, such as Sea Grant, and agencies including the Navy, Coast Guard, Environmental Protection Agency, and National Science Foundation. Because of the many participants in some of the programs it is possible to identify only the principal investigators in the main text. A complete list of scientists and engineers for all projects appears on page 34.

The projects, though selected individually, were chosen in the context of national goals which can be achieved in part by the use of undersea systems. Some of these efforts will lay the foundation for longer range programs leading to the solution of major national marine problems. Because of the time required to completely analyze scientific results and because results from MUS&T-supported programs are often part of a larger program, the scientific data in the following pages are not complete. Comprehensive reports of these programs will be published in appropriate professional journals.

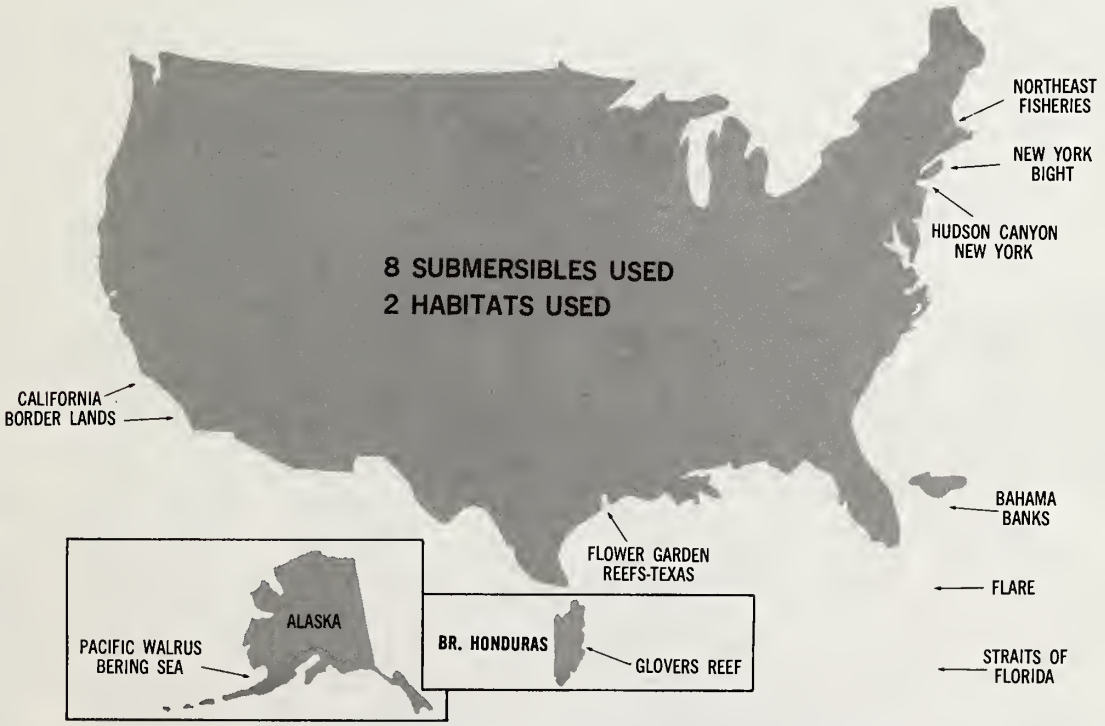


Figure 3.—Fiscal year 1972 MUS&T project locations.

THE NORTHEAST COAST FISHERIES INVESTIGATION

Phase 1

Principal investigator.—Richard Cooper, National Marine Fisheries Service, Boothbay Harbor, Maine.

Associate investigators.—Twelve scientists from Massachusetts Division of Marine Fisheries, Maine Department of Sea and Shore Fisheries, and NOAA.

Location.—Gulf of Maine.

Dates.—September 13–26, 1971.

Facilities used.—Research submersible *PC-8* (fig. 4.).

Objectives:

1. An assessment of the ecological conditions affecting recruitment of New England herring.
2. Determination of the effectiveness of submersibles for biological research.
3. Observation of behavior and population dynamics of lobster.

Results.—Thirty-three research investigation dives were made to depths of 50–750 feet: 14 off the central coast of Maine and 19 in the western Gulf of Maine.

Early Life History of Herring

1. Main herring spawning was 1–3 weeks after the *PC-8* dives were completed. Egg beds were not found at any of the historical spawning sites or adjacent locations.
2. Physical characteristics (depth, water clarity, current velocity, and type of substrate) of historical herring spawning sites were defined. It was demonstrated that divers can work safely at these locations (within the Gulf of Maine).
3. Schools of adult herring were observed and demonstrated strong avoidance reaction to the lights of the submarine. Future use of submersibles to observe herring spawning will require sitting on ocean bottom with lights off. Ambient light levels are sufficient to observe such behavior during daytime.
4. Collections of herring larvae and eggs from the bottom will be possible with nets and scoops, fished from the submarine. The reactions of herring larvae, at the time of capture, to the plankton net are definable.

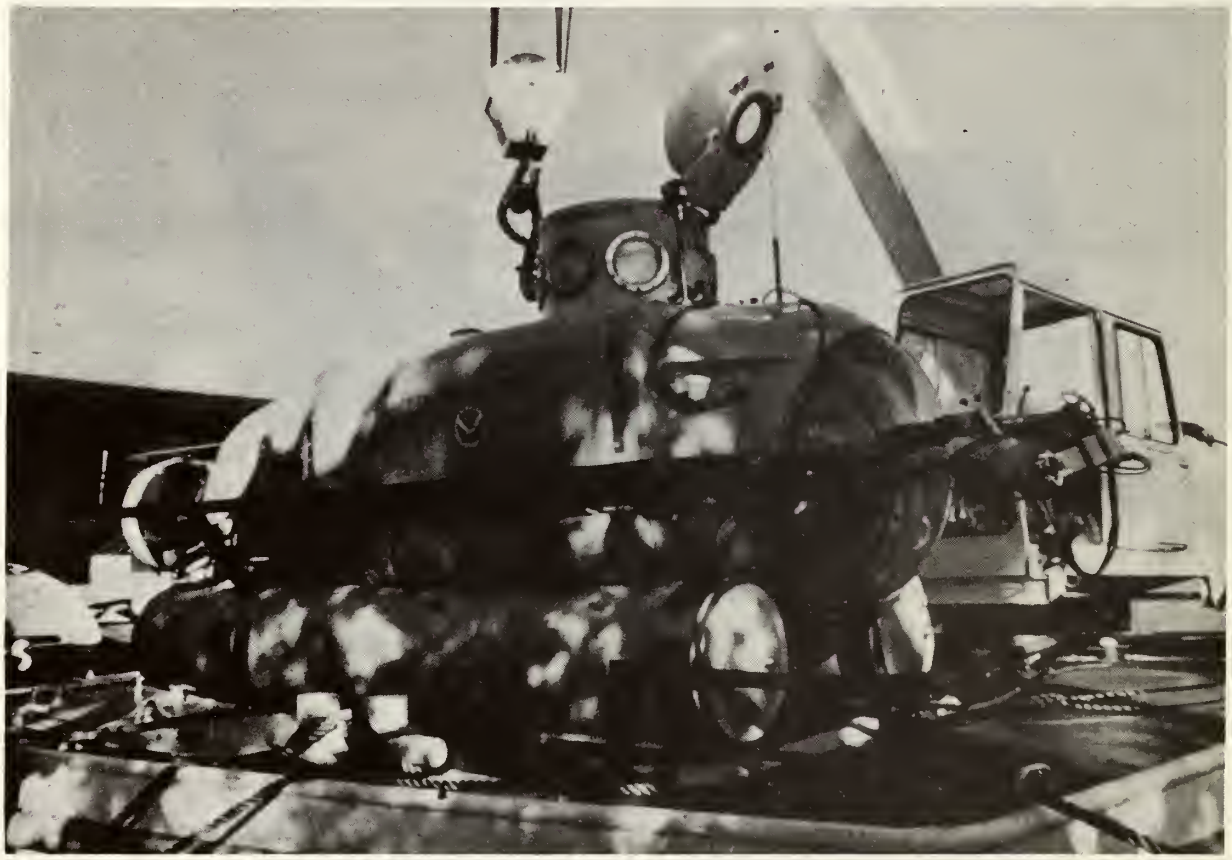


Figure 4.—Research submersible *PC–8*.

Characteristics of Ocean Bottom

Bottom type was photographically documented at each dive location over the range of depths traversed. Bottom types ranged from clean bedrock, rock, or sand at 50–100 feet, relatively firm mud with occasional outcrops of bedrock or rock rubble and covered with a thin veneer of silt from 100 to 400 feet, and soft mud/silt or mud/clay bottom at 400–750 feet.

Characteristics of Bottom Fauna

1. The population densities of 18 bottom-oriented species of finfish and crustaceans were identified; these species did not demonstrate strong avoidance reactions to the submarine.
2. Estimates of density for species that inhabit holes in the bottom or burrows under rocks are minimal estimates.
3. Ecological observations were made on the following:
   a. Lobster (*Homarus americanus*)
      1. Lobsters or signs of lobster activities (lobster burrows) were not present, with one exception, at depths in excess of 250 feet. There were, however, sufficient rock cover and mud burrows to provide shelter similar to that occupied by lobsters in shoaler water.
      2. Lobsters were not observed on Stellwagen Bank, a large, shallow (50–200 ft), rocky bank.
      3. Commercial concentrations of legal-sized lobsters (up to 30,000 lb per km^2) were discovered in mud burrows on the channel bottoms (100–200 ft) of estuaries. Evidence of lobster shedding was observed at these locations, where water temperatures are 12°F colder (48°F vs. 60°F) than the shallow depths of 0–60 feet where all shedding was previously thought to occur. Fishermen were apparently not aware of such quantities of lobsters in these areas in the autumn.
      4. Juvenile lobsters do not extend beyond depths of approximately 150 feet. An inverse relationship was evident between relative abundance of juvenile lobsters (up to 1 lb) and predator fish such as sculpins, goosefish, and cod.
      5. The reactions of a 2-pound lobster, taken by the mechanical arm of the *PC-8* at a depth of 750 feet, were observed during a rapid ascent to the surface. This individual demonstrated no signs of distress en route to the surface, suggesting that lobsters do not suffer the "bends." Fishermen hypothesize, however, that a rapid change in pressure may in part cause lobster mortality on the offshore fishing grounds.
      6. Solar light was highly visible to the human eye at depths to 750 feet. The extensive seasonal migrations of the lobsters over the Continental Shelf may be directed, in part, by the penetration of light to the ocean floor.
   b. Shrimp (*Pandalus borealis*)
      1. Adult shrimp frequent a muddy bottom with males predominating at 100–200 feet and females below 300 feet.
      2. Shrimp were evenly distributed over the ocean bottom with concentrations up to 25,000 lb/km^2.
      3. When adult shrimp were disturbed by the *PC-8*, they jumped off the bottom for a distance of 1–3 feet, then settled immediately back to the bottom. They quickly walked down into the gouge marks in the mud made by the submarine or the otter boards of a bottom trawl to feed upon dislodged invertebrates.
      4. Shrimp were not associated with mud burrows at this time of year.
   c. Hakes (*Urophycis* sp.)
      1. In terms of biomass, hakes were the most abundant forms of fish life on the bottom. Maximum concentrations reached 14,000 individuals per km^2 or 70–100,000 lb/per km^2.
      2. Hakes were common inhabitants of mud burrows from 100 to 750 feet.
   d. Goosefish (*Lophius americanus*)
      1. Goosefish were most abundant on the mud to sand bottoms at both general dive areas. Maximum concentrations reached 1,250 per km^2 or 50–75,000 lb per km^2.
      2. The abundance of large goosefish (average weight 60 lb) in the deeper waters may be the reason for a low lobster population at these depths. The goosefish is a known predator of the lobster and can easily consume individuals up to 4–5 pounds.
   e. Redfish (*Seabastes marinus*)
      1. Redfish were associated primarily with rock outcrops on a muddy bottom, with 30–40 percent of the individuals seen intimately associated with rock shelters.
      2. Redfish were observed at all depths from 150 to 750 feet.
   f. Wrymouth (*Cryptacanthodes maculatus*)

      The wrymouth was commonly observed in the burrows of the clay/mud bottom at depths of

550–750 feet off Provincetown, Mass. They were not observed at other dive locations.

g. Octopus (*Octopus bairdii*)
Large concentrations were observed moving over the bottom or within the entrances of burrows in the clay/mud substrate at depths of 500–750 feet off Provincetown, Mass.

h. Euphausid shrimp (*Nyctiphanes norvegica*)
Dense arrays of euphausid shrimp were observed buried within the upper several millimeters of silt overlying all mud bottoms at depths of 150–600 feet. Concentrations approached 50,000,000 per km^2 or approximately 250,000 lb per km^2.

i. Deep sea red crab (*Geryon* sp.)
Red crabs were observed oriented sideways within the entrance to burrows in the western Gulf of Maine at depths of 300–750 feet.

Phase 2

Principal investigator.—R. Cooper, National Marine Fisheries Service (NMFS), Boothbay Harbor, Maine.

Associate investigators.—Twelve scientists from the Fisheries Research Board of Canada, Environmental Protection Agency (EPA), Maine Department of Sea and Shore Fisheries, and National Oceanic and Atmospheric Administration (NOAA).

Location.—Gulf of Maine.

Dates.—May 20–June 13, 1972.

Facilities used.—Research lockout submersible *DEEP DIVER* (fig. 5).

Objectives.—To provide extensive training in deep sea saturation diving and submersible lockout techniques, and to perform various elements of scientific fisheries research.

Results of the training objectives:

1. Trained three two-man teams in submarine lockout.
   a. Teams 1 and 2 to 300 feet, breathing air to 150 feet and helium-oxygen ($He-O_2$) to 300 feet.
   b. Team 3 to 100 feet, air only.
2. Trained team 1 in saturation while breathing $He-O_2$ at a depth of 150 feet with excursions to 250 feet.
3. Trained all personnel in diver support such as decompression chamber operations, including decompression, pressurized mating and unmating of submarine to the deck decompression chamber, launch and retrieval of submarine, and support boat functions (diver safety and communications).
4. Evaluated saturation diving versus bounce diving from surface, using air and $He-O_2$ breathing mixtures.
5. Evaluated dry-mode observational capabilities of *DEEP DIVER*, compared with the submersibles *PC-8, ALVIN*, and *DEEP STAR 4000.*
6. Made 29 dives, 19 of them short-duration lockout dives. Two dives were saturation excursions to an average depth of 186 feet, and eight were made for scientific observation.

Results of the research objectives:

1. Macrobenthos sampled by divers and using standard surface sampling gear were compared, including detailed photographic documentation and processing of samples. The objectives were 90 percent realized.
2. The bottom water mass was physically and chemically defined, and the environmental monitoring unit performed reasonably well.

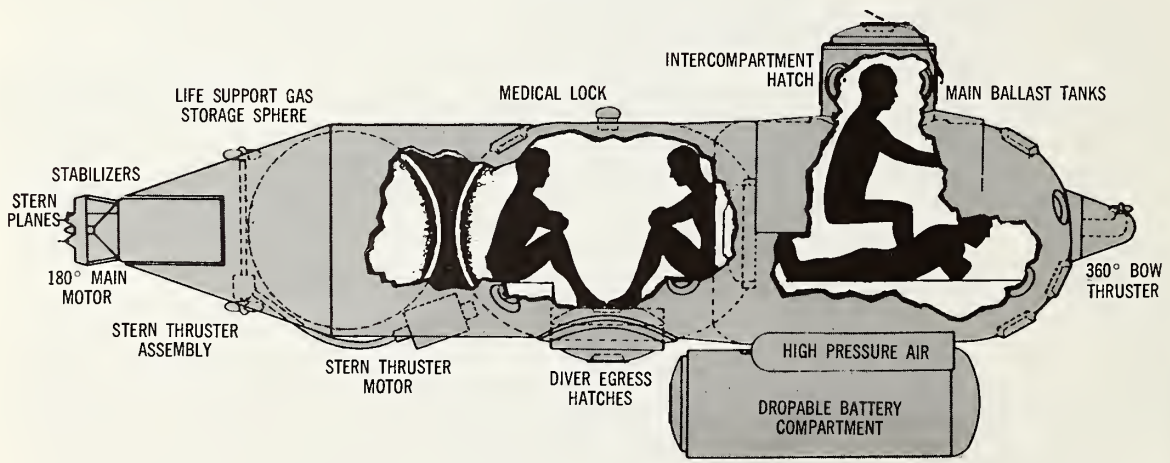


Figure 5.—Research lockout submersible *DEEP DIVER*.

3. "Mud" and "rock" populations of lobsters were compared through photographic documentation of habitat. Hardware breakdown cancelled three diving days scheduled for this objective. Diver lockout on a mud/silt substrate proved very hazardous, with the submarine settling into the mud while the divers were locked out. New information was collected on the behavior and ecology of lobsters in relatively deep water (150–300 ft), demonstrating the presence of a commercial concentration in the mouths of estuaries, as seen during the previous fall dives.
4. Trace element and pesticide concentrations in macrobenthic organisms were sampled, as these relate to the proximity of a land mass. Samples were submitted for processing by EPA.
5. The northern shrimp, *Pandalus borealis*, was studied with special reference to distribution related to the physical and biological characteristics of the ocean bottom. For the first time evidence was collected showing that some adult shrimp occupy small mud burrows.

General comments.—The mission was hampered by poor weather on the surface and extremely low water temperatures which ranged from 42°F on the surface to about 38°F at the deepest locations. Because of this cold and the inability of the divers to remain in the water in a saturated mode for any length of time, the saturation portion of the mission was cancelled and most of the scientific portion was carried out using nonsaturation lockouts from the submersible. With this technique approximately 75 percent of the scientific objectives were realized. The problem of diver cold further emphasizes the need for technological research before efficient long-exposure science projects are possible in northern latitudes.

NEW YORK BIGHT PROGRAM

Phase 1

Principal investigator.—D. Swift, Atlantic Oceanographic and Meteorological Laboratory (AOML), NOAA.

Associate investigators.—J. Malone, Old Dominion University; D. Duane, Corps of Engineers; and scientists of the National Marine Fisheries Service.

Location.—Coastal areas near New York City and New Jersey.

Dates.—September 30–October 7, 1971.

Facilities used.—Research Submersible *PC-8*.

Objectives:

1. Examination of the New York City dump site to determine the extent, thickness, and continuity of the spoil areas.
2. Examination of the Hudson shelf valley and adjacent shelf floor as a preliminary reconnaissance for a long-term study of sediment transport.
3. Examination of the ridge and swale topography south of the shelf area.

Results.—Fifteen submersible dives were completed despite rough weather caused by hurricane Ginger.

The complex superimposition of small-scale ridges and swales at small angles to the large-scale form seems to have involved both the incision of the large-scale forms and the construction of attached tails and streamers of sand. The *PC-8* dives in this Bight area revealed a distribution of grain sizes similar to that observed on the Virginia shelf. Troughs are floored by coarse, pebbly sand and fine-grained sand; locally, outcrops of semiconsolidated clay substrate are exposed. Fine-grained flank sands became coarser up the sides of ridges, ending in well-sorted, medium-grained sand on the crests. This topography has been heavily modified by the posttransgression hydraulic regime. At present the ridges appear to be maintained by strong, intermittent currents which scour out troughs and the fair-weather wave surges which winnow the crests. A dive to the Veatch and Smith scarp on the west flank of the north New Jersey shelf valley revealed bare gray clay substrate thinly veneered with coarse, rippled sand and clay pebbles at a depth of 150–125 feet, then a cap of sand, grading from fine sand at its base to medium sand at the crest at 100 feet. A dive several hours earlier to the nearby Sea Mew scarp had revealed active lingoid ripples of fine sand moving directly down the scarp in response to the rotary tidal current, then at its maximum velocity. Despite such intermittent movement of sand into the valleys, the sand caps have not been flattened. The valleys have not been filled, but merely veneered by a coarse lag deposit.

Phase 2

Principal investigator.—D. Swift, AOML, NOAA.

Associate investigators.—Fifteen scientists from NMFS, Corps of Engineers, Smithsonian Institution, Vassar College, Barnard College, and Westinghouse Corporation.

Location.—Coastal areas near New York City and the central New Jersey shelf.

Dates.—July 4–31, 1972.

Facilities used.—Research submersible *DEEP STAR 2000* (fig. 6).

Objectives:

1. Continue to study the dynamic processes of sediment transport in the New York Bight.
2. Observe the conditions existing at the New York dredge spoils and sewage sludge dump sites.
3. Study fish ecology.
4. Evaluate a proposed new dump site.

Figure 6.—Research submersible *DEEPSTAR 2000*.

Results.—Six successful scientific dives were completed to depths of 150 feet. Current meters with long-term recording devices were emplaced at four locations, to be retrieved at a later date. The biological party made two dives. The first, at the sewage sludge dump site, revealed only three species of macrofauna. The water was filled with black, flocky material about 4–5 mm in length and 2 mm in diameter. Essentially, no current was observed. The sediment on the bottom appeared to consist of two layers. The first was 1/4–1/2 inch thick and was of a browner color than that below it. The lower layer consisted of sand mixed with sludge, the organic portion being no more than 10–20 percent by volume and less by weight.

The second biological dive, at a proposed dump site, revealed a much greater population of fauna than had been anticipated, resulting in the recommendation that the site not be used as a dump.

Four successful geological dives were conducted on the central New Jersey shelf to search for evidence of bottom sediment transport and of the origin of the ridge and swale topography of the area. Daytime dives were complemented by side-scan sonar profiling at night. This combination proved very effective, as the side-scan sonar revealed areas with significant bottom configuration which led the investigators to important dive sites. Streaks on the sonar record turned out to be carpets of old shells which could not possibly be living in the area at present and must be lag deposits winnowed out of the substrate as currents eroded the troughs into the sea floor. Thus, the shell streaks may be important clues to the origin of the ridge and swale topography, and it is possible that their patterns will reveal the structure of the generating currents.

THE HUDSON CANYON INVESTIGATIONS

Principal investigator.—G. Keller, AOML, NOAA.

Associate investigators.—Nine scientists from Woods Hole Oceanographic Institution and Lehigh University.

Location.—The New York Bight area, 100 miles due east of New York City.

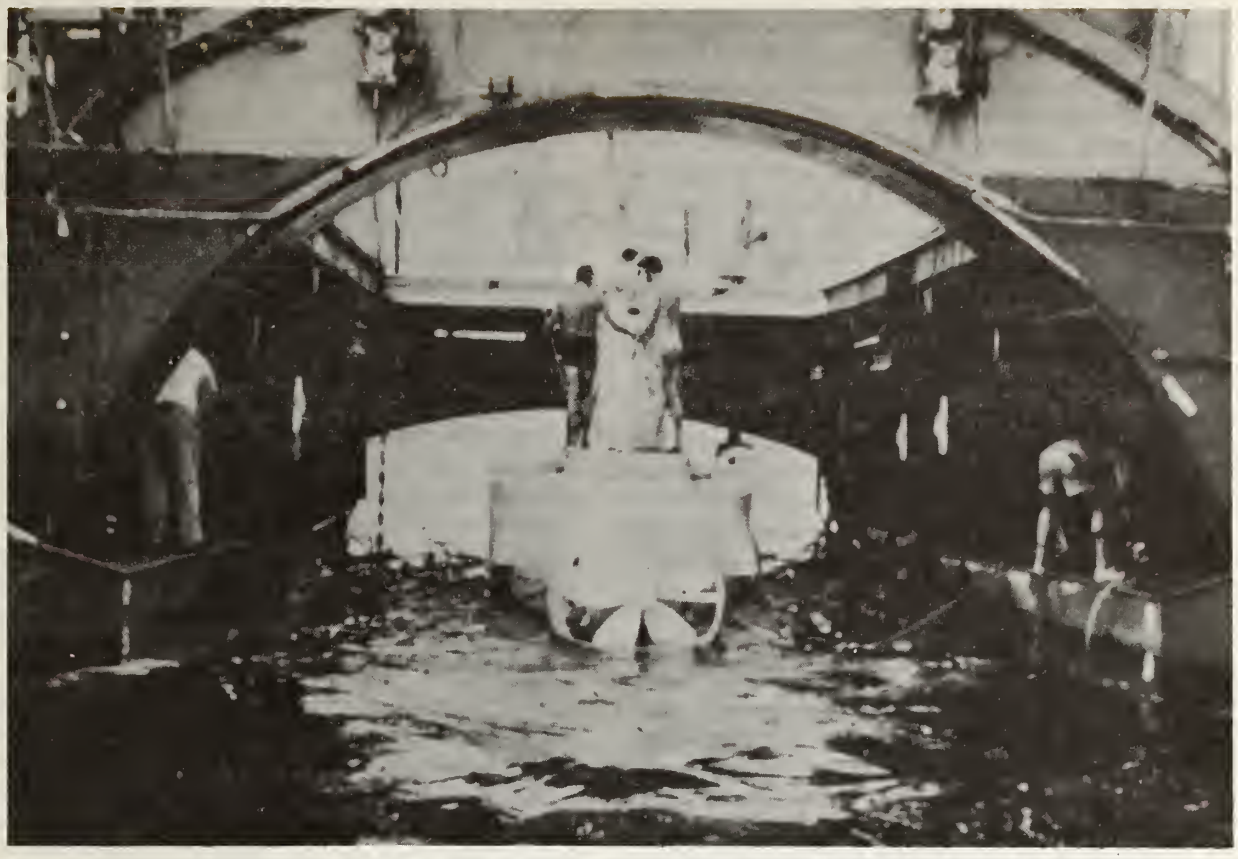


Figure 7.—Research submersible *ALVIN*.

Dates.—June 19-26, 1972.

Facilities used.—The research submersible *ALVIN* and support vessel *LULU* (fig. 7).

Objectives:

1. An investigation of the extant dynamic processes active in submarine canyons.
2. Studies of the sedimentary processes taking place within the canyon by measuring bottom current and sediment transport and by photographically recording the dimensions and lineation of bottom features such as ripples and scour pockets.
3. In-place surface sediment density measurements.
4. Physical and chemical analysis of sediment cores.
5. Measurements of bottom currents and suspended sediment concentrations.
6. Study of benthic biota and their concentration and influence on sediment stability.
7. Stratigraphic sampling of the canyon walls in order to develop the geological history of the canyon.
8. Geophysical studies from surface vessels to determine the structure and overall depositional environment of the canyon.

Results.—A basic result of this mission was support for the belief, widely shared by marine scientists, that most canyons may serve as channels for the movement of sediment and sinkable pollutants from the Continental Shelf to the abyssal depths. The *ALVIN* dives included seven short transects across various sections of the canyon ranging in depth from 350 to 6,000 feet. The *ALVIN* provided the unique capability of selectively collecting sediment cores and rock samples, made short-term current measurements at a large number of sites, and photographed a large number of bottom localities. Special samplers were also used from the *ALVIN* to collect bottom-dwelling organisms in order to determine their types and densities as well as their possible influence on the stability of the sediments.

Preliminary analysis of the dive results indicates that, with the exception of the canyon head, the length of the canyon is being filled in with fine-grained material. In the relatively shallow head portion of the canyon the bottom is firm and

composed of silt and sand-sized sediment and is now an area of erosion. Bottom currents in this portion of the canyon trended downslope (south to southeast) at velocities of 0.30–0.46 knots.

The central portion of the canyon (within the depths of 1,000 to 2,500 ft) appears to be where most of the recent fine-grained material is being deposited. Here the bottom was found to be extremely soft, having a very fluffy appearance and easily thrown into suspension. Because of the concentration of suspended matter, visibility was very poor, varying from zero to 8 feet, and changed rapidly as though turbid water masses were pulsating through the area. Observations indicated that the turbid mass was restricted to a bottom zone extending to 15 feet above the bottom. This plume of turbid water possibly could be the remnant of a turbidity flow down the canyon earlier in the week, when a tropical depression passed over the area resulting in very high seas.

Bottom currents ranged from 0.10 to 0.40 knots and varied in direction from upcanyon during one series of observations to downcanyon 2 days later. Sediment cores collected from this portion of the canyon gave off a strong odor of hydrogen sulfide when opened, indicating high organic content and anaerobic condition within the sediment.

The outermost part of the canyon (3,500 to 6,000 ft) appeared to be a zone of very slow deposition, where very fine-grained sediment composed the relatively cohesive bottom. Bottom currents frequently were not sufficient to be recorded, and only on a very few occasions did velocities reach as high as 0.05 knots. Visibility here as well as in the head of the canyon ranged from 15 to 30 feet. During this initial phase, *ALVIN* also was used to plant a bottom-mounted current meter in the canyon axis at 1,500 feet and to place a series of reference stakes in the bottom.

A second series of dives in September 1972 will afford additional observations in the canyon with particular interest in sediment movement in the vicinity of the reference stakes and to retrieve the current meter. With the assistance of Lehigh University scientists sediment density will be measured in place in order to determine mass physical properties that control the stability of the bottom material.

In summary, based on initial observations, it appears that fine-grained sediment, high in organic content, is moving across the Continental Shelf out to, and being deposited in, the Hudson canyon. Relatively little of this material is being deposited in the canyon head, and only slightly more reaches the outer limits of the canyon. Most of this fine-grained material is being deposited in the central portion of the canyon. Indications from this study are that the canyon does appear to serve as a pipeline for transport of fine-grained sediment from the Continental Shelf out to deeper depths.

BAHAMA BANKS RESEARCH PROGRAM—SUBMERSIBLE INVESTIGATION

Principal investigators.—R. Dill, Manned Undersea Science and Technology, NOAA; R. Dietz, Atlantic Oceanographic and Meteorological Laboratory, NOAA.

Location.—Waters near Freeport, Bahamas, and near Golden Cay, off Nassau, Bahamas.

Dates.—December 2–8, 1971.

Facilities used.—Research submersible *PC-8*; research submersible *ALVIN*.

Objectives.—To study the nature of the fore-reef slope of a carbonate platform, and to look for evidence of a lowered sea level during the last ice age when vast amounts of oceanic water were stored on the continents as ice sheets.

Results:

The *PC-8*.—The six dives ranged in depth from 50 to 790 feet (maximum working depth of the *PC-8* is 800 ft). Currents along the reef escarpment that form the Northwest Providence Channel off Freeport were variable and ranged from still water to a 1/2-knot current flowing to the west. Dives at the same time of day over the 7 days of observation showed that the change in velocity was not of tidal origin. Further, water masses that were marked by strong thermoclines[3] exhibiting "shimmer" at the boundaries had markedly different current velocities.

Of geological importance were the well-developed, fan-shaped rock formations which lapped up on the vertical escarpments of the reef platform. Off Freeport the fan has built up to 300–400 feet and extended a series of gullies 5–20 feet deep and up to 30 feet wide that ran perpendicular to the slope. Recent calcarious sediment forming in shallow water was observed actively flowing down the gullies as small riverlets of moving sand. The walls of the gullies were composed of coarse calcarious sand and some blocks of reef material. The entire surface of the fan was hard and crusty. Efforts to break pieces of fan from the reef failed, apparently because of recementation of fan sediment.

Caves and ledges were common all along the vertical escarpment from 120 to 400 feet. These could have formed during lowered sea level. The fan had built up to cover any evidence of sea level that might have resulted from a lowering below 400 feet.

Terraces cut in the reef platform at 40 feet, 60 feet,

[3] A thermocline is the boundary between two water masses of different temperatures.

90 feet, and 120–135 feet were similar to terraces cut from many other continental margins around the world.

The blocky, coarse-grained fan rapidly building up at the base of the reef off Freeport and the high organic productivity of the region make an excellent model to relate to ancient reefs of the Caribbean, Gulf of Mexico, and central U.S.A. which may indicate oil deposits. The sedimentary relationships observed in this region should be helpful in the planning of drilling programs and in predicting the productivity of similar ancient reefs.

The same depth relationship of the offshore terraces indicates that the Bahama Carbonate platform is seismically relatively stable.

The *ALVIN.*—The *ALVIN* dive was made to a depth of 2,200 feet approximately 1/2 mile west of Golden Cay in the Tongue of the Ocean. A traverse was made shoreward up a consolidated dissected fan of fine to coarse sediment that sloped 15° to 60°. Significant were the large angular blocks of reef rock up to 20 feet high and 50 feet long that had slid out and over what appeared to be recent fine-grained sediment. These blocks must have slid at least 1/2 mile from their point of origin. Ripple marks were observed in the sediments covering the large blocks, indicating episodic currents in deep water. There was only a slow drift of water along the bottom during the dive, and this was incapable of moving sediments to form the observed ripples.

The fan gave way abruptly to a vertical, overhanging rock wall at about 1,200 feet. Ascending along the wall, light became apparent at about 1,000 feet and was associated with an increasing number of sessel organisms. At 650 feet a well-developed terrace with a flat, approximately 60-ft-wide surface was encountered. Various gullies in the fan, similar to those off Freeport and with similar deposits of sand, indicate that a high volume of calcarious sediment is being produced in the upper lip of the Tongue of the Ocean and is rapidly being carried into the deep sea. The nature and mass physical properties of this sediment and the diagenic changes taking place after deposition need further study, as they are important in determining where oil may be deposited in the ancient reef structures of similar nature. The only way of making the necessary measurement is from a submersible because of the varying, rugged topography associated with this environment.

BAHAMA BANKS RESEARCH PROGRAM—HABITAT PROGRAM

Participants.—Listed under "Missions."

Location.—One mile offshore of Freeport, Grand Bahama Island, British Bahamas.

Dates.—December 1971–June 1972.

Facilities used.—*HYDROLAB* habitat and auxiliary equipment (fig. 8).

Figure 8.—*HYDROLAB* underwater habitat.

General objectives.—Detailed, in situ study and analyses of the ecology of the flora and fauna extant in the vicinity of the *HYDROLAB*'s location on the Bahama Banks.

Mission 1

Principal investigators.—W. High and I. Ellis, National Marine Fisheries Service, and W. Schroeder, Texas A&M University.

Date.—December 1971.

Duration.—Six days.

Objectives.—To observe the effects of fish trap design, bait type, trap location, and time of day on the size and type of fish caught.

Results.—Based on observations during *TEKTITE II*, the scientists expected fish to move along natural coral channels. This behavior could be used to advantage to lead fish toward traps placed at the ends of such channels. In the Bahamas, however, this phenomenon was not so pronounced, and the placement of traps at channel ends did not enhance catches.

Although bait type has been assumed to play an important role in attracting fish into traps, no differences were found between the catches of traps baited with cactus, crushed sea urchin, fish meal, conch, and chopped fish. Moreover, unbaited traps caught as many fish as baited traps. Once fish were in baited traps, they immediately attempted to escape and ignored the bait. Large groupers, snappers, and sharks were attracted to traps containing small, live fish.

A preliminary study was made of zooplankton populations associated with the coral reef complex and sand flats immediately adjacent to the *HYDROLAB* site. Plankton samples were taken with nets attached to a hand-held underwater diver propulsion vehicle (DPV) at several depths above the reef top and at a depth of 30 feet above the reef at noon and midnight. Diver-held lights and a 1,000-watt light mounted on *HYDROLAB* attracted great numbers of plankton organisms, which were collected in a similar manner. Large differences were found in both types and numbers of organisms at different times of day. Standard surface sampling would not have shown the stratification and movement of zooplankton into and out of the bottom.

Mission 2

Principal investigators.—L. Somers, D. Macurda, and G. McBride, University of Michigan.

Dates.—May 8–17, 1972.

Objectives.—To determine the ecology of the Comatulid crinoids, the zonation of intralittoral marine algae, and the effectiveness of saturation diving with the *HYDROLAB* underwater habitat.

Results.—The shallow-water crinoid fauna on the southern edge of Grand Bahama Island contains four taxa. The first, *Analcidometra*, is a rare rheophilic species that clings to a purple gorgonian. The two species of *Nemaster, N. Discoidea* and *N. rubiginosa*, are the dominant members of the crinoid fauna. They are apparently excluded from shallow water by a limited tolerance for higher energy. They first occur near 40 feet and increase threefold in abundance by 80–85 feet. At the latter depth they are exceedingly numerous, and over 200 can be counted and censused in 50 minutes. They are rheophobic; the calyx is hidden and the arms are randomly directed into the water. The pinnules are arrayed in a tetrad, and the deployment of tube feet is both diurnal and nocturnal. A variety of solid substrates are used to cling to. *N. discoidea* is the more abundant of the two, which Meyer often found to be the case in the Caribbean. *N. discoidea* tends to occur in the less prominent position on the sides of the spurs, whereas *N. rubiginosa* occurs most commonly near the crest. The fourth species, *Comactinia echinoptera* var. *valida*, is solely nocturnal. Its pinnules are arrayed in one plane, and it hides the calyx deeper in cryptic niches than *Nemaster*. At least some of the deeper water crinoids of the Florida Straits and Northwest Providence Channel and in Jamaica are different taxa and display rheophilic habits in contrast to the shallow-water rheophobes.

Algal zonation on coral heads and the spur and groove region of the reef near the habitat was studied, and a checklist of algae species found in the region was compiled. The coral heads and spur and groove coral regions were divided into zones based primarily on incident light intensity, and the dominant and incidental algae species in each zone were determined. Green algae predominated in zones of highest light intensity, and brown algae in zones of low light. Red algae were particularly scarce in the region studied.

A general conclusion of this mission was the confirmation that diver-scientists trained in basic SCUBA diving and who have limited diving experience can safely participate in a saturation dive, providing they are properly supervised.

Mission 3

Principal investigators.—E. Corcoran and R. Curry, University of Miami.

Dates.—May 19–26, 1972.

Objectives.—To gain a better understanding of the relationships involved in the delicate balance between reef organisms and the chemistry of the surrounding water.

Results.—Water samples were obtained, and many chemical analyses were made in situ using experimental procedures developed at the University of Miami Rosenstiel School of Marine and Atmospheric Sciences.

Mission 4

Principal investigator.—J. Bunt, University of Miami.

Dates.—June 1–7, 1972.

Objectives.—To develop detailed bathymetric transects of the microrelief of the bottom, using a grid network as a reference, and to establish the diversity patterns of the coral network.

Results.—Using this grid system, samples of bottom material including its living organisms were obtained and frozen for later chemical analysis. This study of the benthic community is part of a long-range program at the University of Miami Rosenstiel School to define the ecology of reef communities and relate their biological composition to the existing chemical and physical properties. Various aspects of these studies are supported by NSF and AEC.

Mission 5

Principal investigators.—A. Pilmanis, V. Pilmanis, and R. Given, University of Southern California.

Dates.—June 11–17, 1972.

Objective.—To further document the physiological responses of humans to saturation diving and underwater habitat living with respect to (1) fluid volume regulation, (2) the effects of increased partial pressure of O_2 in inspired gas, and (3) stress.

Results.—Fluid volume regulation was studied in order to determine the effects of daily excursion dives from the habitat amounting to an average of 5 hours' immersion per subject per day. Urine specimens taken immediately following excursion dives of varying lengths demonstrated both a water and an osmotic diuresis in all three subjects. An average weight loss of 4.0 pounds per person was also noted over the 7-day period. This weight loss probably resulted from a combination of factors including long daily immersion periods, low-fat diet, physical exertion, and stress. The orthostatic intolerance tests proved negative, indicating no significant blood volume loss from the extensive immersion times during the saturation dive.

The breathing medium of the *HYDROLAB* underwater habitat was air at ambient pressures which resulted in a partial pressure of $O_2(PO_2)$ of 367 mm Hg. The decrease in hematocrit value and red blood cell counts and the increase in serum enzyme levels was probably related to the elevated PO_2. However, because there was no change in the vital capacities of the three subjects and no complaints of substernal distress at any time, the decrease in red cells was considered part of an adaptive process to the hyperoxic environment and not signs of chronic oxygen toxicity. The data from this experiment indicate that the saturation period could be safely extended for more than 7 days.

The reactions of the three subjects to the stresses of saturation diving and habitat living were measured by serum enzyme levels and plasma cortisol and aldosterone. All three subjects showed a slight increase in lactic dehydrogenase, and one also showed an apparent increase in serum glutamic oxalacetic transaminase and serum glutamic pyruvic transaminase. Plasma cortisol was above the normal range in one of two subjects measured, but plasma aldosterone showed a gradual decrease in the two subjects during the in-dive period. It was concluded that stress was minimal during the USC *HYDROLAB* saturation dive.

FLORIDA AQUANAUT RESEARCH EXPEDITION (FLARE)

Participants.—B. Walden, Program Coordinator, Woods Hole Oceanographic Institution; J. G. VanDerwalker and R. F. Dill, MUS&T, Scientific Coordinators; scientific investigators listed with each mission.

Location.—Southeast Florida.

Dates.—January 27–April 17, 1972.

Introduction

Although the scientific teams that took part in FLARE pursued different research goals, their primary objectives were similar: To increase scientific understanding of coral reef ecology to a point where the living reef can be used as an indication of marine environmental health and to test under operational conditions technological advantages to be realized from a movable habitat supported by a surface vessel. Research programs were conducted on the sea floor and on the surface.

The individual projects represent such disciplines as geology, chemistry, biology, physics, and physiology. Along with the scientific data collected, each research team gained information and experience relating to techniques of conducting research from an ocean floor habitat. The expedition also provided valuable training for a large number of ship-based personnel.

Facilities used.—The principal equipment used for this project was the *EDALHAB*, a three-person underwater habitat designed and constructed as a project of the University of New Hampshire's Engineering Design and Analysis Laboratory, and the research vessel *LULU* owned by the United States Navy and operated by the Woods Hole Oceanographic

Institution. The *LULU* is the mother ship for the deep submergence research vessel *ALVIN* and, as such, is equipped with a large-capacity hoisting system for raising and storing the habitat. Figure 9 is an artist's conception.

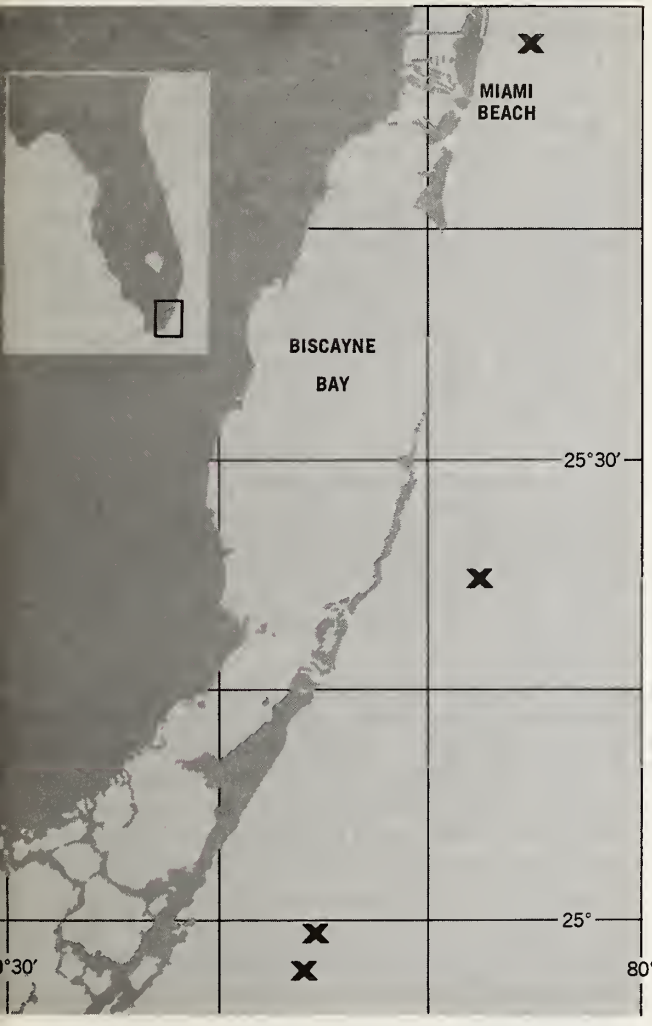
The *LULU-EDALHAB* combination is a unique habitat system in many ways. The habitat is a minimum-cost, student design with little of the sophistication and resulting complexities of the more costly habitats. Its small size and light weight made it ideal for an application requiring portability. The *LULU*'s catamaran configuration and large-capacity hoist system made it an excellent choice for the role of transporting and supporting *EDALHAB*. The vessel's size provided ample space for the equipment and personnel associated with the operational and safety aspects of the projects as well as a platform for surface-based experimentation. The habitat and vessel were further described under "Undersea Habitats and Laboratories."

Flare Science Missions

Four sites along the southeast coast of Florida were chosen for the project (fig. 10). A detailed description of each mission follows.

Figure 9.—*EDALHAB* underwater habitat operating with support ship *LULU*.

Figure 10.—Florida Aquanaut Research Expedition (FLARE) dive sites.



Mission 1: Response of Fish to Traps and Natural Leads

Principal investigator.—W. L. High, National Marine Fisheries Service (NMFS), Seattle, Wash.

Associates.—I. E. Ellis and G. Loverich, NMFS.

Location.—Long Reef.

Dates.—January 27–31, 1972.

The aquanauts, all from NOAA's National Marine Fisheries Service Center at Seattle, Wash., made numerous excursions in reef waters around the habitat, observing at close range the behavior and reactions of different species of fish to trapping and holding devices installed on the sea floor. The research centered on the development of new traps which would improve commercial catches. The program is a continuation of a long-term experiment begun several years ago at the Seattle Center. The parent program was augmented by data collected during the 1970 *TEKTITE II* project off the Virgin Islands and from the Bahama Banks Habitat Program using the Perry *HYDROLAB* off the Grand Bahama Islands.

During FLARE the team reported sighting a great profusion of small marine life at the reef and caught a large number of reef fish in a relatively short time in the traps. But large fish were rare; apparently, the reef area had been overfished, depleting the larger fish in the region.

Mission 2: A Comparative Study of Community Metabolism on Natural and Polluted Coral Reefs. I

Principal investigator.—J. M. Wells, then of School of Medicine, University of North Carolina.

Associates.—A. Wells and J. G. VanDerwalker, MUS&T.

Location.—Long Reef.

Dates.—February 6–10, 1972.

This project sought to analyze in precise detail the makeup of an uncontaminated coral reef and fix a pattern of metabolic rates against which the "state of health" of a reef under the influence of manmade pollutants could be measured.

Among the many devices used during this study were six plastic domes (8 in. to 4 ft in diameter) which were placed over portions of the living reef and sealed. Once in place, the domes had the effect of isolating separate coral communities. Instruments on the outside of the domes recorded oxygen pressure changes and light and temperature conditions within the enclosures. The domes automatically ventilated when oxygen levels became too high or too low.

On the basis of the measurements obtained, calculations of photosynthesis and respiration rates (community metabolism) were possible. The team also used various kinds of sensors to measure and record the physical properties of seawater at different depths and locations. Such data were automatically recorded on readout instruments within the *EDALHAB*. Results are discussed under Mission 4.

Mission 3: Defining the Age and Origin of the Reeflike Structures in 20 Meters of Water in the Upper Florida Keys

Principal investigator.—C. Emiliani, University of Miami.

Associate investigators.—R. A. Gifford (on-site chief scientist), NMFS, NOAA; S. Cawthon and E. Frehsee, Miami-Dade Junior College.

Location.—Long Reef.

Dates.—February 12–17, 1972.

This mission involved the mechanical removal of large quantities of sand from a natural channel in the fore-reef through use of an airlift powered by a high-volume, low-pressure compressor.

Once sand was removed and the bottom exposed, a core of the channel was taken by a hydraulic drill equipped with a diamond corer. The apparatus enabled the aquanauts to obtain a 6-foot-long core of the bedrock of the reef.

This mission was an extension of another study completed in early 1971 at Discovery Bay, Jamaica. Cores taken in each place were to be compared to determine whether growth rates of coral reefs in widely separated areas of subtropical seas are alike. Initial observations at the Long Reef site suggest that the rates of growth seemed different and that close analysis may reveal a contrasting evolutionary pattern. Dating of the core material will give new data on the position of sea level as it rose across the Continental Shelf following the last ice age.

Mission 4: A Comparative Study of Community Metabolism on Natural and Polluted Coral Reefs. II

Principal investigator.—J. M. Wells, University of North Carolina.

Associates.—A. Wells and J. G. VanDerwalker, MUS&T.

Location.—Government Cut.

Dates.—February 18–25, 1972.

The researchers worked with the same ecology-measuring apparatus used on Mission 2. Among the findings were: Miami Beach reef probably loses uncountable units of energy because of clouds of siltation in the upper layers of water, which prevent penetration of essential sunlight. The reef is nearly colorless and almost devoid of the algae that nourishes coral life; large, dead portions probably expired as recently as the last decade. The marine inhabitants differ markedly in species composition from those usually found in and around coral reefs, and almost no juvenile fish were present. The reef appeared deteriorated but not dead, and the reef ecosystem is dramatically different from that of other reefs in Florida and elsewhere in the world.

Since some of the parameters characterizing the reef environment are relatively slow to react to changes in the environment, they may be used as an integrator of environmental conditions. Short-term measurements of such environmental conditions must therefore be used carefully. These studies showed the value of using the living reef community as an indicator of impact on the marine environment.

Mission 5: A Comparison of the Behavior of Fish Around Artificial and Natural Reefs. I

Principal investigators.—H. L. Pratt (on-site chief scientist) and R. B. Stone, NMFS, NOAA.

Associate investigators.—K. J. Pecci and C. D. Newell, NMFS, NOAA.

Location.—Pacific Reef.

Dates.—February 26 to March 2, 1972.

Results.—This mission was a study of a newly emplaced artificial reef covering 646 square feet, made of some 500 discarded rubber tires. NMFS workers had set down the manmade reef in late January. The experiment marked the first time an artificial reef was built virtually beside a natural reef and designed to conform closely to an authentic reef in configuration and environmental aspects.

The main thrust of the two-part survey was close and uninterrupted comparison of the two kinds of reefs—artificial and natural—to ascertain whether manmade reefs took on the same characteristics as natural structures and the speed of the evolution. After completion of the mission, the scientists said the new reef showed every sign of becoming a brand new marine community. Their report supported the belief that young fish, and later adults, migrate rapidly into new habitats if environmental conditions are favorable.

Findings were that the reef had grown as anticipated; fish families present were virtually the same as those on the nearby natural reef and formed a new, not a displaced, population. A fine film of algae, excellent for grazing fish, had covered the artificial reef; and counts of inhabitants of both reefs, by numbers and species, indicated whether they were "transients" or full-time residents of each reef.

Mission 6: Interactions Among Marine Plants and Herbivorous Fishes on a Subtropical Atlantic Reef

Principal investigator.—S. A. Earle, Natural History Museum of Los Angeles County.

Associates.—C. C. Aregood, Trenton State College; Z. Goldstein, Miami-Dade Junior College.

Location.—Elbow Reef.

Dates.—March 28–April 3, 1972.

The aims of this mission were twofold: First, to describe the diversity, abundance, and interactions among the benthic plants and herbivorous fishes in the study area; second, to obtain living deep-water plants for laboratory cultivation leading to pigment and life history analysis. Although severe storm conditions necessitated an early termination of the mission (3 days instead of the intended 5), valuable

information was obtained, including rare observations on the behavior of fishes under storm stress.

More than 100 species of plants were obtained, several representing new records for Florida. Herbarium voucher specimens have been made and will be deposited in appropriate institutions. Approximately 30 species were retained alive and successfully transferred to Trenton State College for cultivation.

At least 18 species of plant-eating fishes were seen in the area, and specific feeding activity was recorded. Grazing was heavy and apparently had a striking influence on the distribution and abundance of plants in the area. Many plant species occurred only in crevices and other protected places. Most abundant were fast-growing filamentous algae of several species and diverse calcareous Rhodophyta and Chlorophyta.

Halfway through the mission, storm conditions apparently caused an abundant influx of filamentous brown algae (*Giffordia*) not previously obtained on the reef. The following day, strands were entangled on various surfaces and were readily consumed by most plant-eating fishes.

A striking lack of large predatory fishes (such as groupers, snappers, barracudas) was noted, although small reef fishes were abundant. Individuals of several species (*Pomacanthus arcuatus, Pomacanthus paru, Holacanthus isabelita, Holacanthus tricolor, Pomacentrus* sp.) were diseased, with fungus evident on the scales or anus. Numerous individuals had eroded or tattered fins. The apparent small numbers of large predators and large numbers of small fishes, including distressed individuals, suggests a possible correlation. Injured animals are usually quickly consumed, but if predators are reduced in number, chances for survival of weak individuals are greater.

Observations at Elbow Reef are not conclusive, but do raise questions that deserve further study. What causes the fungus, apparently so common at the study area and rarely encountered elsewhere? Is the unusual abundance of small fishes and unusually small number of large predators ordinary for Elbow Reef? What is the influence of fishing on the ecology of the reef? Does the proximity of Miami and other human activity affect the reef? More study is needed on these and other questions raised during the mission.

Mission 7: Synecological Studies of Subtidal Seaweeds in Florida

Principal investigator.—A. C. Mathieson, University of New Hampshire.

Associates.—B. Hutchinson and R. Fralick, University of New Hampshire.

Location.—Elbow Reef.

Dates.—April 3–6, 1972.

The principal purpose of this mission was to study the relation between climate and periodic increases or decreases in quantities of seaweed in subtropical waters and to identify species inhabiting temperate, subtropical, and tropical Atlantic waters.

Vegetation observed on the reef was in a healthy, undamaged state. The high diversity of plant species observed, though heavily grazed by herbivorous fishes, indicated a well-balanced community unaffected by pollution or siltation.

The aquanauts collected seaweed taken from assorted substrate—reefs, sandbanks, and rocky areas—for later quantitative evaluations of distribution and abundance. Also collected were data related to the feeding habits of plant-eating fishes and echinoderms associated with seaweeds and on food preferences of sea urchins.

Mission 8: Quantitative Studies of Coral Reef Fish Communities—Home, Range, Size, and Community Structure

Principal investigators.—C. L. Smith (on-site chief scientist), American Museum of Natural History; J. C. Tyler, Academy of Natural Sciences.

Location.—Elbow Reef.

Dates.—April 7–12, 1972.

The purpose of this mission was to take a fish census of residents and visitors occupying 30 square feet of Elbow Reef in which a number of coral heads were located.

At the end of the mission the ichthyologists reported that the reef seemed in excellent health and alive with 77 species of fish. They reported that "The Elbow" appeared comparable in all respects to similar reefs monitored in Bahamian and other tropical waters. About 22 species made up the permanent reef community, and about 55 transient species passed through repeatedly.

Mission 9: A Comparison of the Behavior of Fish Around Artificial and Natural Reefs. II

Principal investigators.—H. L. Pratt (on-site chief scientist) and R. B. Stone, NMFS, NOAA.

Associates.—F. Steimle and R. A. Clifford, NMFS, NOAA.

Location.—Pacific Reef.

Date.—April 12–14, 1972.

The purpose of this mission was to monitor the artificial reef established in January. Using the biological "blueprint" acquired on the earlier artificial reef studies, production rates of marine animal life in the reef complex were computed. During Mission 5 the beginnings of a resident population were found consisting of quantities of juvenile reef fishes, but no adults and large predators.

During this mission a number of adult fish were observed occupying apparently permanent quarters in the artificial reef, including 2–3-foot-long hogfish and parrotfish weighing an estimated 40 pounds each. Visitors to the reef included mangrove snappers, a valued sport catch. The team counted an additional 8–10 species in the new marine community, bringing the total to some 30 species. A layer of algae and other encrusting organisms had covered the tire surface, providing a new food source for the reef fish and a hiding place for juveniles.

This reef lies within the Biscayne National Marine Monument and will be surveyed four times a year by scientists of the National Marine Fisheries Service working with park biologists to determine the life history of an artificial reef. It is estimated that the total reef population won't become stabilized for at least 5 years.

Several other scientific research efforts used the *LULU-EDALHAB* combination as a platform from which to conduct adjunct experiments in meteorology, physiology, and underwater communications.

Mission 10: A Study of the Transmittance of Broad-Band Solar Irradiance in the Ocean Mining Layer

Principal investigators.—K. Hanson and M. F. Poindexter, Sea-Air Interaction Laboratory (SAIL), NOAA.

Associate.—R. L. Rutkowski, SAIL, NOAA.

Location.—All reef sites.

Dates.—January 27–April 17, 1972.

During the FLARE operation, scientists of NOAA's Sea-Air Interaction Laboratory took measurements of solar radiation penetrating the sea from the surface to the 45-foot depth. Their work entailed continuous measurements by automatic devices installed aboard *LULU*: time lapse color movies of the sky using a fixed "all sky" camera with a 190-degree field of view; measuring solar radiation above the surface with an upfacing and a downfacing pyranometer; and taking water surface temperature with a floating device. Underwater, a pyranometer was fixed at the 45-foot depth to measure radiation after it had passed through waters above. Within the water column—from just below the surface to the bottom—was a "yo-yo" pyranometer with pressure sensors to measure the solar radiation profile in the water.

The radiation data were recorded on paper and magnetic tape and later analyzed at the Miami laboratory. The results show that, even though the transmittance of the water varied considerably from day to day due to changes in turbidity, the average transmittance during these short periods was nearly the same. Because the Government Cut site was expected to be strongly influenced by turbid water resulting from wastes and dredgings, the results collected during a 1-week period suggest that natural variations in turbidity are so large that manmade variations in turbidity are undetectable in these short-term studies. This was the beginning of a long-term study to measure the reaction of the reef populations to the sun's energy for determining the health of a marine environment and the impact of man's pollution on such environments.

Mission 11: Application of Diver Physiological Telemetry System

Principal investigator.—H. R. Skutt, University of New Hampshire.

Associates.—A. Waterfield (on-site chief scientist) and R. Fall, University of New Hampshire.

Location.—Elbow Reef.

Dates.—April 3–6, 1972.

On selected dives, telemetry systems were used to measure physiological changes in divers at different depths and intervals. The telemetry system measures heart rate and skin and internal body temperature at varying depths. The aquanauts being tested wore electrodes and plastic probes to provide data on the efficiency of divers over extended periods in a saturated state. Measurements were transmitted to the *LULU* by a sonar device carried by the aquanauts. Some of the initial temperature measurements indicated that after 3 days underwater the diver's body begins to lose heat at an accelerated rate. These physiological studies indicate where technological efforts must be concentrated, for example, to conserve diver body heat.

Mission 12: Diver Communication

Principal investigators.—H. Rothman and S. Feinstein, University of Florida.

Associates.—Maj. W. Bond and Capt. M. Myatt, United States Marine Corps; Lt. Comdr. E. Shank, Office of Naval Research.

Location.—Pacific Reef.

Dates.—April 12–16, 1972.

The purpose of this surface-based mission was to determine how the efficiency of underwater work might be improved by better communication among divers.

The experiments consisted of a series of 1-hour test periods in which a team of divers assembled a framework of plastic pipes under water. One set of tests was done with communication equipment and one without. The data were recorded and when reduced will become part of a long-term study of the effect of communications on divers.

STRAITS OF FLORIDA SEDIMENT STUDIES

Location.—In the Straits of Florida southeast of Miami.

Principal investigator.—G. Keller, AOML.

Associate investigators.—Eight scientists from AOML, Woods Hole Oceanographic Institution, and University of Miami.

Dates.—October 8–29, 1971.

Facilities used.—Research submersible *ALVIN*.

Objectives.—To investigate present-day sedimentary processes at six specific sites in the Straits of Florida, and to obtain photographic coverage and rock samples.

Results.—A total of 13 dives were made.

AREA A: Dives were made in the outer part of the valleys (23°54.5′N, 82°47.5′W) to a depth of 1,115 meters, where vertical limestone escarpments 30–50 meters high bordered the 100-meter-wide valley, and midway upslope (24°05′N, 82°47′W) to a depth of 873 meters. At the latter site no major relief was found, and there was a definite infilling of the valleys by fine sediment (silt and clay). Bottom currents in the valleys were observed moving southward (downslope) at a speed of 3cm/sec.

AREA B (Undulating seafloor topography, western Pourtales Terrace): The two short dives, of 4 hours each, comprised a west-to-east transect across a series of bottom undulations in the vicinity of 24°16.5′N, 82°23′W. The features appear to be old valleys which have been and are being filled with fine sediment. The area is unmistakenly a depositional environment. Bottom currents were found to flow from east to west at velocities ranging from 12 to 23.4 cm/sec.

AREA C (Sink hole on the Pourtales Terrace): A successful dive was made into one of two sink holes located on the outer edge of the Pourtales Terrace. The hole measured approximately 1,000 meters in diameter and extended 105 meters below the surrounding sea floor. Bottom currents on the Pourtales Terrace measured 14.3 cm/sec flowing to the west southwest. The sink hole has vertical walls with a sand-covered, ripple-marked floor. Scour by bottom currents has resulted in a moatlike trench around the base of the walls. Within a 3-hour period bottom currents varied greatly from essentially zero velocity to 26.5 cm/sec. Currents appear to flow in over the lip of the sink and circle around on the bottom of the hole. The sink hole bottom is at a depth of 407 meters.

In each of the dive areas bottom currents were found either 180° or 90° out from the Gulf Stream's flow. A definite counter current to the Gulf Stream was found at the dive sites.

AREA D (Knolls and depressions on the eastern Pourtales Terrace): Owing to the difficulty in maintaining station with the R/V *LULU* (because of the Gulf Stream) and the relatively small size of the knolls, it was not possible to dive at this site.

AREA E (Eastern margin of Straits of Florida, near Orange Key, Bahama Islands): Two dives were carried out in the vicinity of 25°00′N, 79°15′W to investigate a series of east-west trending ridges. These features were found to be very gentle bottom undulations which are being blanketed by fine-grained carbonate mud. Bottom currents ranged from 5 to 9 cm/sec., flowing to the northeast. This is an area of deposition rather than erosion and not an area of sand wave development as proposed by earlier investigators.

AREA F (Irregular bottom topography west of Little Bahama Bank): A series of five dives was completed in the area just west of Little Bahama Bank to determine the origin and present processes responsible for the anomalous bottom irregularities in this area. Instead of the prominent east-west fabric shown by bottom contours in previous investigations, a dominant north-south trend was observed for these features. Very sharp ridge crests were common, as were near-vertical walls, some of which displayed a relief of 35 to 40 meters. In many places the ridges appeared to result from the buildup of crusts which are trending parallel to the flow of bottom water. Bottom currents as great as 22 cm/sec were recorded flowing to the north. A submarine canyon cutting as much as 80 meters into the sea floor was found extending westward from the edge of the Little Bahama Bank. Bottom currents in the canyon were flowing upslope to the east at velocities of 7–9 cm/sec. Ripple marks not only support these measurements of an eastward flow but also indicate that velocities greater than 9 cm/sec are active in the canyon. Sand collected from a depth of 483 meters in the canyon consisted essentially of very shallow water material, e.g., halimeda fragments, indicating that the canyon is the avenue along which sediments from Little Bahama Bank are transported down into the Straits of Florida. On the sea floor adjacent to the canyon, current flow was to the north.

Miami Terrace: A dive was made to the lower portion of the eastern face of the Miami Terrace to investigate the geological history of the terrace by sampling the outcropping strata. The intent was to obtain in-place rock specimens with the *ALVIN* drill in order to define the stratigraphic horizon(s) of the Miami Terrace. This would allow geologists to extend the geological time line seaward for miles in this area and aid in understanding the formation of the terrace. The dive was deeper than planned, and it was not

possible to traverse and sample all the localities as originally hoped. The drill obtained only a very small sample, but served to break off rock from the outcrop.

TEXAS FLOWER GARDEN REEF SURVEY

Participants.—The Marine Biomedical Institute of the University of Texas Medical Branch, the Flower Garden Ocean Research Center, Texas A&M University, University of Texas at Dallas, Smithsonian Institution, and Lamar University; R. Alderdice, Marine Biomedical Institute, Program Coordinator. Approximately 15 scientists participated.

Location.—Various reef areas in the Gulf of Mexico, 120 miles southeast of Galveston, Tex.

Dates.—June 5-12, 1972.

Facilities used.—Research submersible *NEKTON GAMMA* (fig. 11).

Primary objectives:

1. Investigate the biological zonation and sample the biota of the West Flower Garden to a depth of approximately 500 feet.
2. Investigate and sample the geological structure and sedimentological zonation of the West Flower Garden to a depth of approximately 500 feet.
3. Investigate the heavy metal and chlorinated hydrocarbon content, distribution, and zonation in sediments and selected faunal species.
4. Investigate organisms living symbiotically with sea urchins on the West Flower Garden Coral Reef.
5. Continue the investigation of surface currents across the Texas continental shelf, utilizing drift bottles.
6. Emplace a long-term water current recorder.

Secondary objectives:

1. Evaluate techniques for conducting a major sedimentological sampling program on the continental shelves.
2. Investigate the applicability of a small research submersible to evaluate candidate research areas in the open sea.
3. Evaluate the tools and techniques utilized for sampling and documenting scientific observations during a submersible dive.
4. Evaluate operational techniques for efficiently utilizing submersible time.
5. Evaluate operational techniques for efficiently utilizing a submersible dive.

The scientists found the flora and fauna of the reef to be more abundant than expected and noted several

Figure 11.—*NEKTON GAMMA* with sample bag attached to reel. Sampling arm is directly in front of sample bag.

new varieties unknown to exist in the area. Drowned reefs were found at greater depths than expected, and an absence of exposed bedrock was noted. Fine sediment accumulation at depths of about 400 feet indicated little or no bottom current. Also, no manmade detritus or other effects were noted.

A total of 16 dives were completed during this mission. Of major significance was the terrain as viewed at the lower reaches of the dome slope. Prior to this manned observation, grabs and dredges had only partly prepared the investigators for details of geological and biotic structure which their visual inspection revealed.

Immediately after the Flower Garden Reef mission another submersible cruise using the *NEKTON GAMMA* was made to investigate several natural gas and oil seeps off the Texas coast. The 5-day cruise, beginning on June 12, included participation of representatives of the Flower Garden Ocean Research Center, Texas A&M University, and the Smithsonian Institution. Its objective was to observe, photograph, and recover sediment samples from four widely separated dive sites, but the developing storm off the Yucatan peninsula, which later became hurricane Agnes, caused considerably rough seas and prevented diving on all but one day. Although three dives were made, only a few gas bubbles were sighted. They were not continuous, and their source could not be confirmed. Further investigations will be necessary to increase the scope and amount of data that should be gathered.

GLOVERS REEF CARBONATE PLATFORM STUDIES

Principal investigators.—R. Ginsburg and N. K. James, University of Miami.

Associate investigators.—Six scientists from Colorado School of Mines, University of Texas, and University of West Indies.

Location.—British Honduras, barrier reef and atoll.

Dates.—December 1-6, 1971.

Facilities used.—Research submersible *NEKTON BETA* (fig. 12).

Objectives.—Geological and biological exploration of the fronts of living reefs to study their origin and composition.

Results:

1. Twenty-nine dives were made, covering three prime study areas.
2. In two of the study areas, thoroughly cemented sediment believed to be contemporary was collected. This supports the hypothesis that

Figure 12.—*NEKTON BETA* and hoist.

cementation plays a major role in forming and maintaining the steep slopes of reefs.

3. A vertical to overhanging cliff with projecting ledges and a zone of large caves were observed at 375–400 feet. It is suspected that the cliff was sculptured by shoreline wave erosion as sea level fell and rose during the Pleistocene-Holocene.
4. Substantial but variable amounts of reef talus were found. On the windward side of Glovers Reef this talus occurs at depths below 400 feet. On the barrier reef and the leeward side the talus appears as blocks of rock from the cliff, some as large as 50 feet.
5. The major reef-building corals are absent below the first major break in slope at 250–280 feet. The green algae *Halimeda* extends to 380 feet, and the crustose coraline algae to 850 feet. This is the first precise documentation of the lower limit of reef builders.

SOUTHERN CALIFORNIA BORDERLANDS

Principal investigator.—E. H. Shenton, Plessey Industries; J. Warme, Rice University; F. P. Shepard, Scripps Institute of Oceanography.

Associate investigators.—Scientists from Lockheed Corporation and Plessey Environmental Systems, Ocean Research Center, and MUS&T personnel.

Location.—Southern California coast.

Dates.—June 24–28, 1972; July 10–17, 1972.

Facilities used.—Research submersible *DEEP QUEST* (fig. 13).

Objectives.—Objectives were to determine the condition of the bottom and the overall effects of some 25–30 years of dumping in this area. This study is part of an overall program designed to determine the role of submarine canyons in the dispersal of solid wastes. Three dives were made in the Santa Cruz, San Pedro, and Santa Catalina Basins to investigate environmental and sea floor conditions at three ocean dumping sites containing low-level radioactive, chemical, and industrial wastes respectively. Plans included data gathering by coring and in-place shear strength measurements. A fourth dive was made to plant a current meter in the axis of the La Jolla Canyon and to familiarize NOAA and Environmental Protection Agency personnel with *DEEP QUEST*'s underwater capabilities. Dives 5 and 6 were made to study the geology and geologic processes in the Coronado Canyon Fan Valley and the Outer Coronado Gorge. The remaining two dives were made

Figure 13.—Research submersible *DEEP QUEST* aboard support ship.

to investigate geological/biological conditions in the San Clemente Basin and the San Clemente Escarpment.

Results.—The eight research dives covered 40 hours of bottom time to depths of 6,700 feet with the following detailed results.

DIVE 1

The primary objectives of the first dive were to survey a low-level radioactive waste dumping site in the Santa Cruz Basin at a depth of 6,300 feet and observe the effects of the wastes on the environment and sea floor. Samples of sea water, sediments, and biological specimens were collected. Salinity, temperature, and depth were measured throughout the dive, and 70- and 35-mm photographs of the bottom were taken.

Although approximately 3,000 barrels of radioactive waste are recorded to have been deposited within a 1.5-mile radius of the dive area, only a few barrels were encountered during the entire course of the dive. Of the barrels encountered, only two could be clearly identified as containing radioactive waste. Preliminary conclusions are that the wastes were not dumped in the designated areas or that they were scattered over a much larger area than reported.

Visual observations and photographs were taken of the bottom life and debris. Four test stations were established on the sea floor, the last station being where the only radioactive material was found. Water samples and cores were obtained at three of these stations, and a complete series of in-place vane shear tests were made at the first and last stations. Salinity, temperature, and depth data were collected throughout the entire dive area.

DIVE 2

The second dive was made in the San Pedro basin to 2,900 feet near the center of a 3-mile circle that had been designated as a waste chemical and industrial ocean site in 1946. The purpose was to observe the ocean bottom conditions and debris and to sample sea water and sediments. Although records listed large quantities of containerized chemicals and industrial waste material as having been dumped at this site, sonar and visual search showed no greater concentration of refuse than is generally found elsewhere at similar depth. A striking contrast was apparent, however, in that the area was nearly devoid of live fish and bottom-dwelling organisms. Dead fish, shrimp, and other animals were frequently encountered, but small gastropods were the only living animals seen.

Five stations were occupied in a line as the search progressed shoreward from the center of the dump site. Cores for biological, chemical, and mineralogical analysis were taken at each station, along with in-place vane shear measurements and water samples. Also the bottom was photographed, and salinity, temperature, and depth were recorded throughout the entire dive.

DIVE 3

The principal purpose of this dive was to survey the ship garbage dumping site 7.5 miles south of Santa Catalina Island in 2,400 feet of water and to observe the effects of the wastes on the environment and sea floor. During the dive, depth, temperature, and salinity were continuously recorded, and several water samples were collected throughout the water column and while on the bottom. Although an approximate 5-mile traverse of sea floor area was investigated, only a relatively small amount of waste material was observed. A core sample of the bottom sediments for biological, chemical, and mineralogical analysis was collected at each of the six stations, and a series of vane shear measurements were made at the first station. Also photographic records of bottom traversal were obtained.

DIVE 4

The objectives of the fourth dive were to plant a current meter for Scripps Institute of Oceanography in the axis of the La Jolla Canyon and familiarize NOAA's and EPA's representatives with *DEEP QUEST*'s underwater operations. Salinity, temperature, and depth were continuously recorded throughout the dive, and several water samples were collected at various depth intervals and while on the bottom. Also, 70-mm and 35-mm photographs were taken of the sea floor area traversed.

DIVE 5

This dive was in the Coronado Canyon approximately 7 miles southwest of the Mexican Coronado Islands. The main purposes were to investigate the canyon's geology, observe submarine erosion within the canyon, plant a current meter on the canyon axis, and obtain some cores and in-place vane shear measurements. Also, 70-mm and 35-mm stills and 16-mm motion pictures of the canyon length traversed were obtained. Except for planting the current meter (because of parting of the release line), the objectives were accomplished.

During the dive *DEEP QUEST* traveled down the canyon axis for approximately 2 miles from the starting point. The canyon proved to have a meandering course with horseshoe bends and walls of moderate slope. The rock outcrops and clumps encountered along the canyon walls were composed of semiconsolidated sediments (mud or sandstones). Based on CTFM sonar information the canyon width generally varied from 200 to 300 yards and in some places to 400 yards.

Several stations were taken during the course of the dive for specific geological and biological observations. At the first, two excellent cores were obtained in conjunction with three vane shear/penetration tests. An additional core was obtained at the last station at a depth of 4,212 feet. Penetration tests at the first station indicated distinct lenses of stiffer or coarser sediment at intermittent depths below the sediment surface.

Biological observations revealed an extensive and varied quantity of life throughout the canyon lengths traversed, the most abundant form being the brittle stars. Other forms sighted were several members of the family Scorpaenidae, hagfish, rat-tailed fish, a couple of crabs, some fan corals, several varieties of Holothurians, and some sea pins.

Salinity, temperature, and depth were also measured throughout the dive.

DIVE 6

This dive was in the Outer Coronado Gorge a few miles farther down the Coronado Canyon axis from the area investigated on dive 5, but with the same objectives including a second attempt to plant the current meter and to collect some rock samples.

During the dive *DEEP QUEST* traveled down the canyon axis for approximately 2 miles, but found navigation slightly more demanding because the canyon not only meandered but also had many precipitous drops along the floor. Also its width decreased to less than 100 yards in some places. It was on this dive that *DEEP QUEST* brushed against the wall of the gorge, severely damaging the brow instrument rack and the starboard propeller shroud.

Geological observations indicated that the canyon floor was generally covered with muddy sediment and occasional solid rock outcrop. Solid rocks were also encountered along the slopes and canyon walls, and a rock cliff extending upward for several hundred feet was found at the end of the dive. There were no signs of active currents, hence the canyon may not be eroding at the present time.

Biological observations indicated abundant numbers of brittle stars and jellyfish, a few fan corals, and an occasional fish.

Salinity, temperature, and depth data were gathered throughout the dive, and numerous 35- and 70-mm photographs and 16-mm motion pictures were taken. All scientific objectives were accomplished, except for planting the current meter and obtaining rock samples.

DIVE 7

The objective of this dive was to sample and observe geological and biological conditions in the deepest water within reasonable distance from San Diego. The study included investigating and sampling burrows and sedimentary structures in soft sediments, observing and sampling rocks for study of rock-boring organisms, and possible correlation of rocks in deep offshore areas with known formations on nearby land areas.

The initial bottom location was in the desired area at a depth of only a few hundred feet less than the deepest in the basin. A northeast traverse carried the observers up out of this deep area and over depth contours enclosing a geomorphic and an effective sill. Cores were taken at four sites, and rock samples were collected near the end of the dive at the base of the escarpment at a depth of 5,500 feet. No evidence was found that the sill depth (6,000 ft) affected the abundant bottom life in the axis of the basin; circulation must extend to the bottom.

Throughout the dive motion pictures and stills were taken, and salinity, temperature, and depth were recorded on magnetic tape for later analysis.

DIVE 8

The objectives of this dive were to extend the previous investigations. Geological and biological observations were to be continued along the steep rock scarp, almost 5,000 feet high, on the east side of the San Clemente Basin. Samples of sedimentary rocks with evidence of rock-boring organisms were collected at different depths up the scarp. Also, boring and erosion of the rock outcrops by marine dwellers were closely observed.

At the beginning of the dive *DEEP QUEST* descended to 5,580 feet, a depth slightly greater than the shallowest point reached on the previous day's dive. Stations were made, and rock samples were collected with the manipulator arms as *DEEP QUEST* made its way up the steep slope. The top of the scarp was finally encountered at a depth of 1,620 feet. No cores were recovered because the coring device had to be removed due to rugged terrain and anticipated rock bottom. A variety of rocks were recovered, including sandstones near the base, basalts at middepths, and phosphorite near the top. Movies and still photographs were extensively taken throughout the dive, and salinity, temperature, and depth were monitored intermittently.

PACIFIC WALRUS STUDY

Principal investigator.—G. C. Ray, The Johns Hopkins University.

Associate investigators.—Two scientists from Johns Hopkins University, one from Arctic Health Research Center, and four from University of Alaska.

Location.—The Bering Sea, west-northwest of Alaska.

Dates.—February 21–March 27, 1972.

Figure 14.—*PC–8* operating through ice.

Facilities used.—Research submersible *PC-8* (fig. 14) and a U.S. Coast Guard icebreaker.

Objectives.—The objectives were to use a submersible as part of integrated research on the Pacific walrus, involving primary productivity, benthic productivity, chemical and physical oceanography, and walrus behavior and ecology. Research was integrated under the U.S. International Biological Program which has support from the National Science Foundation and the Office of Naval Research.

Results.—Nine dives were made to 100–300-foot depths. The scientists studied the aspects of the food chain from phytoplankton to benthos to the Pacific walrus, *Odobenus rosmarus*. The walrus population structure, social behavior, and reproductive biology were also examined. The *PC-8* made four long-duration scientific dives and five test dives in a program of intensive benthic sampling and inspection and to observe walrus feeding behavior. Some 3,000 walruses were sighted during the cruise. Their movements, vocalizations, feeding, and resting schedules and the organization and activities of mating groups were studied intensively. Feeding itself was not observed, but an abundance of broad furrows and pits, apparently made by feeding animals, was sighted on the bottom from the submersible. The massive bioturbation caused by the walrus while feeding on the bottom might increase the return of the nutrient organic material locked in the sediments back into the biological food chain.

The operational problems and solutions encountered while working under arctic conditions provided the MUS&T office with valuable data for working with submersibles in cold-water environments and indicated where new technology is required.

INTERNATIONAL PROGRAMS

Efforts in international programs consisted primarily of establishing contacts and basic areas of interest which could be pursued as the overall MUS&T program develops. Progress is as follows:

1. MUS&T is a participant and will partially

support a program to explore the mid-Atlantic ridge. This program is being supported jointly by the National Science Foundation, the U.S. Navy, and the French government. The project is called FAMOUS—French American Mid-Ocean Undersea Study.

The French bathyscaphe *ARCHIMEDE* and the French submersible *SP-3000* will take part in the dives with the U.S. submersible *ALVIN*. The three submersibles will explore the rift valley, where volcanic eruptions, submarine springs, and frequent earthquakes are believed to mark the tearing apart of the Atlantic floor. The project is expected to reach its climax in the summer of 1974, when some 40 dives into the rift are projected. The scientific direction of the program is coming from Woods Hole Oceanographic Institution.

2. Initial contacts have been established with representatives from the Federal Republic of Germany and the U.S.S.R. for the purpose of discussing the possibility of future joint undersea programs. Both the Germans and the Soviets have expressed considerable interest in joint programs which would involve cooperative efforts with ocean floor laboratories. It is anticipated that additional meetings will lead to joint operational programs.

During the summer of 1972, personnel from the University of New Hampshire, under contract to MUS&T, visited the German underwater laboratory in Cuxhaven, Germany, and the Draeger Company in Lübeck. In July an MUS&T consultant visited the Biological Institute in Helgoland where programs of mutual interest were discussed.

3. Because of the basic problems involving underwater biomedical requirements, close liaison has been established (with the cooperation of the U.S. Navy) with biomedical experts in the United Kingdom, Sweden, and Japan. Agreements have been reached with regard to using common data bases for acquiring biomedical data, particularly in areas concerned with long-term health problems. Studies of common interest have been generated with Japan through the auspices of the Panel on Diving Physiology and Technology of the U.S./Japan Bilateral Committee on Natural Resources. Continued cooperation in the biomedical field is anticipated with all of the above nations.

Participants in Scientific Programs

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BAHAMA BANKS SUBMERSIBLE INVESTIGATION

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TEXAS FLOWER GARDEN REEF SURVEY

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University of Texas at Dallas.—J. Urban.
University of Texas at Austin.—L. Land.
Smithsonian Institution.—R. Gooding.
Lamar University.—A. Delfache.
General Oceanographics, Inc.—J. Vernon.
University of S.W. Louisiana.—R. Hunter.
Marine Biomedical Institute.—R. Alderdice, D. Bowman.

GLOVERS REEF CARBONATE PLATFORM STUDIES

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University of Texas at Austin.—L. Land.
University of the West Indies.—J. Lang.

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Scripps Institute of Oceanography.—F. Shepard, N. Marshal, P. McLaughlin.

PACIFIC WALRUS STUDY

Johns Hopkins University.—G. C. Ray, S. Sult.
Institute of Marine Science, University of Alaska.—R. Bardsdate, S. Stoker, R. Prentki, E. Miller.
Arctic Health Research Center.—F. Fay.

Plans for Future Programs

Planning was begun in 1972 for new and expanded initiatives in undersea activities that may serve such areas of national interest as:

The National energy sources.—The Continental Shelf may be important reservoirs of oil and gas. Extensive undersea exploration by submersibles and other means is needed to determine the exact locations and extent of such deposits. Underwater surveys will also be necessary to permit efficacious and ecologically sound recovery of such resources. The MUS&T office plans to work closely with private and governmental groups for the rational application of underwater technology in expanding the National Fossil Fuel Inventory and for site surveys of offshore nuclear electrical power plant locations.

Mineral and biostock assessment.—Surveys by the U.S. Geological Survey and private groups have shown that many shelf and estuarine areas are either actual or potential sites of mineral deposits. Similarly, surveys have shown the importance of these regions for the genesis and development of marine food specimens. The MUS&T office is collaborating with fisheries and agriculture groups in planning underwater exploration support.

Establishment of ecological baselines for biostock renewal.—As a counterpoise to biostock assessment for harvesting purposes, it will be necessary to obtain details of the habits and life cycles of food species so that they may be harvested without degradation of the food stocks. As part of this effort, baseline biological studies will be conducted to establish criteria for assessing damage to the marine environment. Extending the FY 1972 program, it is planned to work with conservationists and ecologists, using divers, habitats, and submersibles where necessary. Broad and spot investigations will be made, and the results will be available to concerned user groups.

Advanced physical and geophysical measurements.—The possibility of destructive earthquakes along the Pacific coast of the U.S. (including Alaska) has led to intensified endeavors by seismologists for long-range prediction of such earthquakes. Such a prediction capability will require intensified and widespread seismic sensing, especially in or near the vulnerable west coastal zones. Thus, extensive seismographic arrays may be distributed on the sea floor and shelf area. Manned undersea equipment and vehicles may play an important role in the emplacement, servicing, and retrieval of the seismic instruments. It is planned to cooperate with State and Federal agencies when they need assistance and counsel for underwater work.

The sea floor at depths below 100 feet offers a relatively thermally and acoustically quiescent environment, and the water column is a natural isotropic barrier. Therefore, important experiments in such fields as gravity wave detection and cosmic ray muon measurements can be conducted from fixed and mobile laboratories, or recording cassettes can be placed on the bottom for long periods and then retrieved by divers or submersibles. During FY 1972 discussions with the high energy physics community began.

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